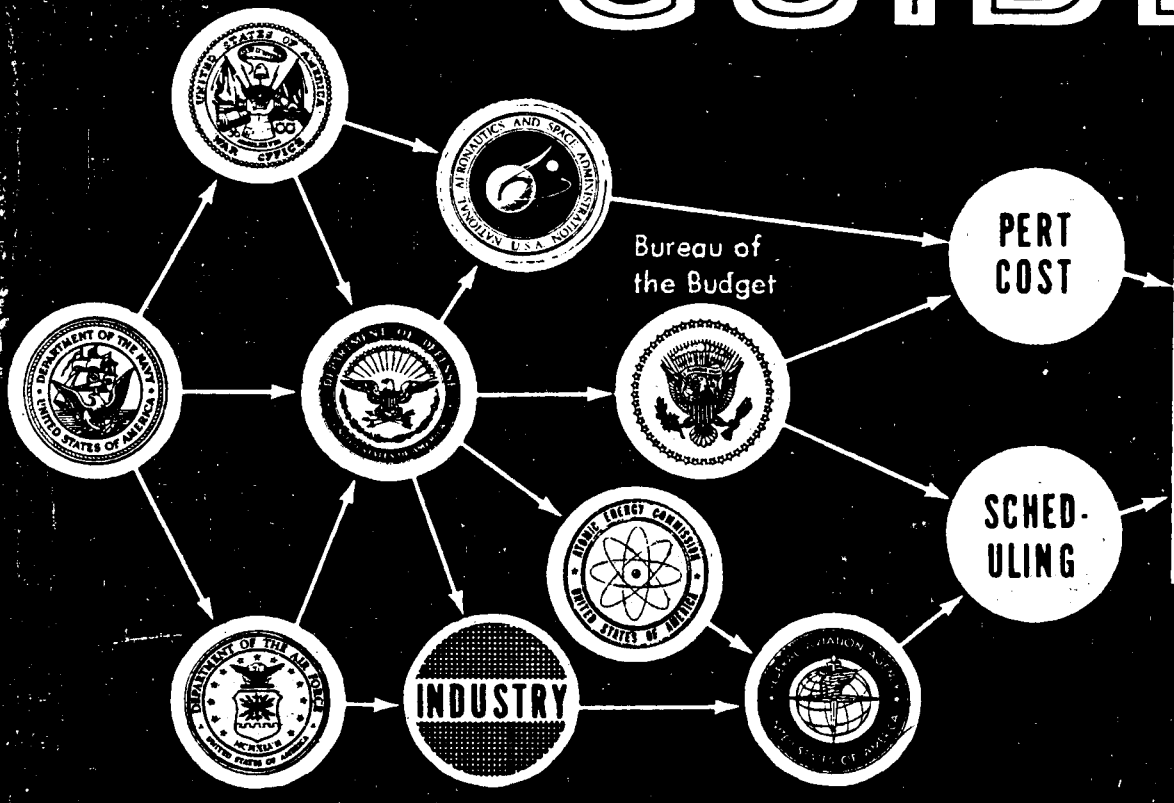
PERT · · ·

GUIDE



MANAGEMENT USE

U.S. DEPT. OF DEFENSE.
PERT COORDINATING GROUP

JUNE 1963

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FOREWORD

Management like invention is no longer a matter of individual effort; Space-Age Programs are too complex. Management of major space, weapons, construction, military or other programs is accomplished through large organizations of professional experts in administration, finance, science, engineering, and production, to list but a few. Each program must be carefully planned, scheduled, evaluated, and managed toward attainment of specific objectives.

The complexity of directing and controlling these programs has challenged conventional management techniques.

A recent study based on analysis of 12 major weapons programs shows an average cost overrun of 3.2 times original bid and an average time span of 1.36 based on the original target. 1/ Overruns create uncertainty in the availability of weapons systems and therefore create uncertainty in strategic plans. Cost overruns on one program may prevent the adoption of other important systems. Such problems in planning and control are not confined to the Department of Defense or to system acquisition. 2/ They are inherent in any complex program and can only be resolved by team effort of professional groups working within the discipline of an effective management system.

PERT represents a significant step toward an integrated management system encompassing the variables of time, resources, and technical performance. The improved planning produced by PERT offers a sound basis for scheduling as a means by which status may be measured and current and potential problems isolated in time to take corrective action. It also provides the integrative discipline for government and corporate managers at all levels necessary for the definition, communication and successful attainment of the prime and supporting objectives of the plan. As a means by which the manager may reduce uncertainities, it provides a set of principles, methods, and techniques to materially assist the manager in achieving his vital objectives.

A Government PERT Coordinating Group has been established to both develop and continuously improve a PERT system that is uniform and promotes better decision making processes in both government and corporate management. This Guide has been prepared under the direction of this Group.

The purpose of this Guide is to:

- establish a basic reference on management and PERT concepts as an improved communication system for all management levels;
- set forth PERT principles and methods for use by managers in the achievement of objective-oriented work;
- stimulate consistency in the regular application and use of PERT in the decision making process and maintain uniformity among government and industrial teams.

Drafts were reviewed by field staffs of the government agencies, the Military Departments, a selection of 27 firms or institutions through their corporate Presidents, and industry associations. All suggestions have been constructive and carefully considered in this final Guide and these contributions of individuals and organizations are gratefully acknowledged. The combined source of knowledge, reviews, and suggestions establishes this Guide as truly authorless.

While some government agencies advocate that the contractor use PERT or PERT Cost for his own management, the National Aeronautics and Space Administration does not advocate specifying how or by what system the contractor shall manage his effort. Instead NASA requires only reporting of summary data in PERT format which can be derived from whatever detailed system the contractor is using for his management. In both basic PERT time and NASA-PERT and Companion Cost, NASA requires only reporting in a prescribed format of summary time and cost data required for total project integration and management by the NASA project manager. The use of PERT, PERT Cost, or PERT and Companion Cost at the contractor level of management, which backs up the reporting to NASA, is optional to the contractor.

Throughout the Guide PERT is used in the generic sense to embrace all variations of networking analysis. Each Chapter relates PERT to a phase of the management process.

PERT COORDINATING GROUP:

Department of Defense	Atomic Energy Commission
Office, Secretary of Defense	Bureau of the Budget
Department of the Army	Federal Aviation Agency
Department of the Navy	National Aeronautics and Space Administration
Department of the Air Force	

1/ "The Weapons Acquisition Process", Merta J. Peck, Frederic M. Scherer, Research Graduate School of Business Administration, Harvard University, 1962. PP 12-13 and Table 2.1 p 22.

2/ Ibid PP 8-9

EXTRACT FROM PRESIDENT'S BUDGET MESSAGE TO CONGRESS, 1963

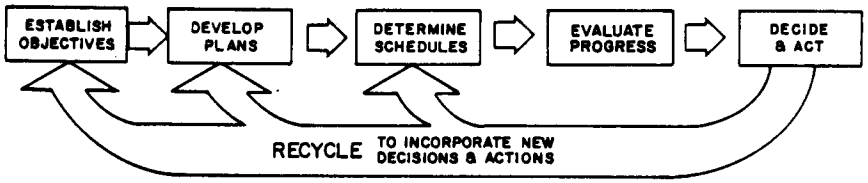
"In our society, Government expects continuing scrutiny and criticism of its efficiency. The search for greater efficiency is never finished. What was an efficient practice a few years ago may be obsolete today. New approaches to work practices, to information handling, and even to decision making itself are the order of the day throughout Government as well as private industry.

"Furthermore, we shall maintain pressure on each department and agency to improve its productivity and efficiency. Through improved management techniques, installations of modern equipment, and better coordination of agency programs, important productivity gains have already been realized, and further advances will be forthcoming. I mean to insure that in each of the various Federal programs, objectives are achieved at the lowest possible cost."

CHAPTER I

PERT AND THE MANAGEMENT PROCESS

THE MANAGEMENT PROCESS CYCLE



A management device or technique, regardless of the degree of sophistication, is only a tool and can never be a substitute for effective managers. The tool or technique must be an integral part of the entire management process. Logically, therefore, in any presentation of a management technique such as PERT, a sound concept of the management process must first be established.

The management process is the result of evolution over many generations of trial and error. Much has been written about the function, environment, and the role of management. Very little has been done to develop and describe an orderly process by which good managers can go about getting things done. This Guide develops and describes a management process as the foundation for utilizing PERT in program management.

The function of management entails the continuous, intelligent direction of others by determining and communicating the prime and supporting objectives of an organization. This function necessarily includes the development and utilization of an integrated time-phased plan of action, demanding reasonable requirements in the way of resources and the subsequent balancing of resources as they are made available and used.

This document emphasizes the distinct form of the cycle of applied effort. The basic steps of this process follow:

- the determination and effective communication of the prime and supporting objectives;
- the development of a coordinated plan of action for the accomplishment of the objectives;
- the conversion of the plan into integrated schedules within allocable resources;
- the regular reporting and concurrent evaluation of progress against the scheduled plan and cost estimates;
- the recycling of the above process to achieve the incorporation of a desired new action into a new cohesive scheduled plan.

Establish Objectives

The determination and definition of objectives is the initial and most important step in the management process, largely because the objectives of an organization are its sole reasons for existence. All organized activity must have as its motivating and guiding force the attainment of some predetermined objective or objectives. The current purpose or purposes of the organization must be the yardstick against which all requirements and accomplishments are measured and evaluated. The progressive passing down of specific coordinated objectives from higher to lower levels of management sets the target for and the authorization of detailed planning effort on the part of the receiving organization.

The importance of the effective communication of concise planning objectives from level to level of responsible management cannot be over-emphasized. (Chapter II) 1/

1/ For further discussion of each aspect of the management process as applied to program management refer to later Chapters in this Guide - in this case Chapter II.

Develop Plans

Given the determination or assignment of an objective, the next step is the development of a plan. The planning function sets forth the nature, sequence, and interrelationships of the supporting objectives which must be accomplished to achieve the prime objective. Planning is primarily concerned with the structuring and relationships of units of required effort. It considers and answers questions of capability by determining in-house versus subcontracting effort. It establishes the feasibility of meeting the directed due date for the successful attainment of the objective. There must be a broad operating plan in existence at the highest level of management to serve as a guide for selection of specific supporting objectives.

This plan must be realistic in its requirements and consistent with the available resources and time. The planning function at each level sets forth the important objectives of the kind, quality, and quantity for the work to be performed. If this planning is not accomplished, there can be no assurance of a coordinated, balanced use of resources. Initial planning considers the required resources, including elapsed time, but does not consider the competition for these resources. 1/

Determine Schedules

Scheduling is the bridge from the planning stage to coordinated, effective implementation. It is the translation of the plan, with its elapsed time estimates, into calendar time. The scheduling function considers the competition for available resources both within and between programs. If the earliest attainable scheduled completion date of the current plan is later than the desired date, the manager will pass the plan to the planners for readjustment. If the planners cannot achieve this, they must determine a new completion date with the next higher level of management.

The goal of the scheduling function is to produce a calendar time-phased plan consistent with desired completion dates for the assigned objectives. This schedule is the vehicle for authorizing effort and resources to be expended. It serves as a basis for the continuous evaluation of progress. 2/

Progress Evaluation

Once the scheduled plan has been activated a formal procedure for the regular reporting of progress against scheduled plan is necessary. A process for the early detection and specific description of a potentially significant problem area while there is still time for management to seek solutions to that problem is required. The management process described in this Guide emphasizes, therefore:

- regular, continuous, evaluation of actual performance against current scheduled plans;
- detection and isolation of significant deviations from the scheduled plan as a forecast of time and cost overrun.

The principle of "significant reporting" effects a great reduction in the volume of statistical reports. By considering only the significant deviations from the scheduled plan, the manager need only obtain a detailed analysis of the specific problem covering:

- what remedial action is being taken and by whom?
- what results may be expected and when?

Management Decisions and Actions

The magnitude and relationships of all desired changes must first be examined in the light of their effect on the scheduled plan. Changes may result from alteration in prime objectives or isolation of the problems at any level of effort. The point of origin of the changes is not so important as the orderly method of authoritative approval and implementation.

Deviations from the scheduled plan may require only a change in schedule. Deviation could however require a change in plans, or even a change in objectives. By concentrating on the most important current or forecasted problems, management can expend its efforts to achieve the maximum potential returns relative to the assigned objectives.

A clear distinction must be made as to new action that is within the authority of the operating organization, and action which calls for lateral or higher authority. The first can be handled by direction; the second calls for a careful presentation of the facts and a request for the action desired. 3/

Recycle

The incorporation of change is achieved by a recycling of the management process to provide a revised scheduled plan. Dynamic recycling is the method of achieving and maintaining management control of objective-oriented effort. The formal progress, reviews, and evaluation meetings held by management with their supporting managers provide an opportunity to accomplish the mechanics of the recycling process. 4/

1/ PERT Guide for Management Use, Chapter III.
2/ Ibid Chapter IV. 3/ Ibid Chapter V. 4/ Ibid Chapter VI.

Definition of PERT

PERT is a set of principles, methods, and techniques for effective planning of objective-oriented work thereby establishing a sound basis for effective scheduling, costing, controlling and replanning in the management of programs.

It employs:

- a product oriented work breakdown structure, beginning with these objectives subdivided into successively smaller end-items. 1/ An example is shown in Figure II. 1; 2/
- a flow plan consisting of all the activities and events that must be completed or accomplished to reach the program objectives, showing their planned sequence of accomplishment, interdependencies, and interrelationships. This is called a network, as shown in Figure III. 1; 3/
- elapsed time estimates and identification of critical paths in the networks; 3/
- a schedule which attempts to balance the objectives, the network flow plan, and resources availability; 4/
- analysis of the interrelated networks, schedules and slack values as a basis for continuous evaluation of program status, forecast of overruns, and the identification of problem areas in time for management to take corrective action. 5/

PERT Cost utilizes the network structure as the common reference for estimating and controlling the cost as well as the schedule of the program. This feature permits more complete measurement of progress and enables managers to appraise more realistically the consequences of alternative courses of action. 6/

This basic PERT technique is flexible enough to effectively encompass a variety of objectives and applications including allocation of resources to serve several concurrent projects. While some differences exist in nomenclature in PERT and CPM (Critical Path Method), for example, which suggest differences in concept, both use the network approach to develop and diagram plans, and both effectively serve the same objectives.

PERT Reports for Management

PERT provides clear concise reports for top management in order to evaluate status of completed work and forecast or isolate potential problems. Reports have been developed which serve both corporate and government management and some are shown in Figures I. 3 thru I. 7.

PERT and the Management Process

PERT aids managers from the inception to the completion of a program. Although PERT can be introduced in any phase of a program, its full potential is realized only when it is utilized in all phases by both government and industry. In this manner, PERT correlates the many aspects of a complete program and provides continuity through each of the three phases:

- Pre-contract Phase.
- Contract Negotiation Phase.
- Contract Management Phase.

Government use of PERT assures industrial management that:

- the objectives of the program and interrelated aspects have been defined, evaluated and communicated before a request for proposal is issued;
- contract awards are made on the basis of definitive analyses and improved evaluations.

Similarly, government management is assured that:

- industry has improved opportunity to plan, bid, and manage a program;
- more precise planning and control over resources exists;
- negotiations can be conducted in a more informed manner.

1/ Product is defined as units of accomplishment. All objective oriented work produces units of accomplishment.

2/ "PERT Guide for Management Use", Chapter II. 3/ Ibid Chapter III. 4/ Ibid Chapter IV. 5/ Ibid Chapters V and VI. 6/ Ibid Chapter VII.

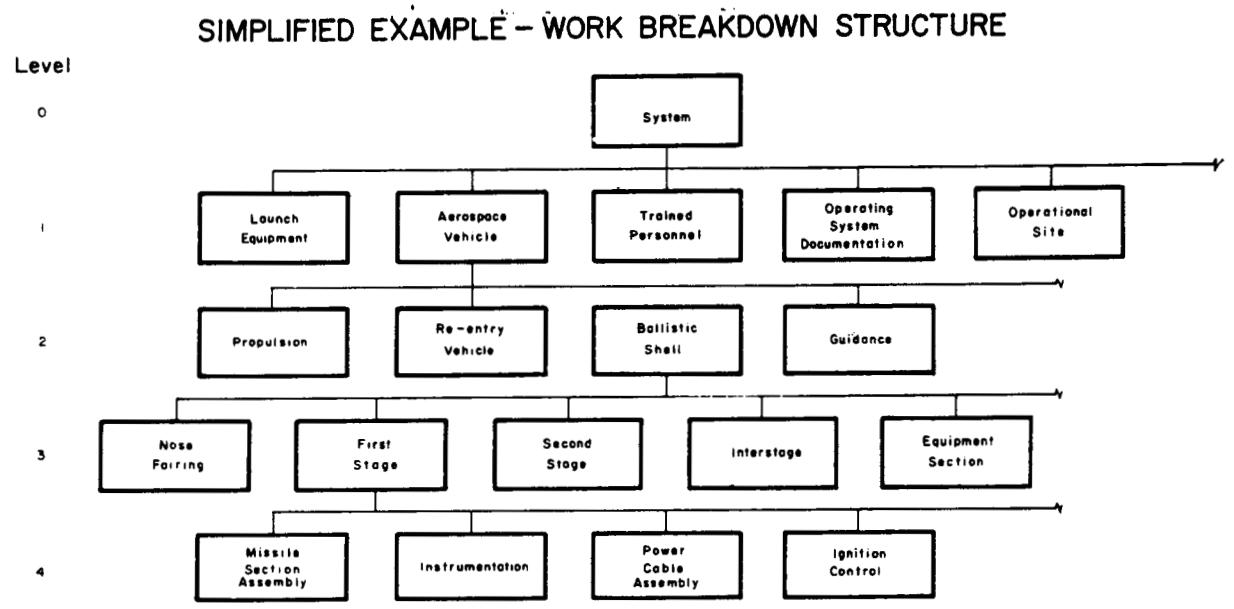


FIGURE I.1

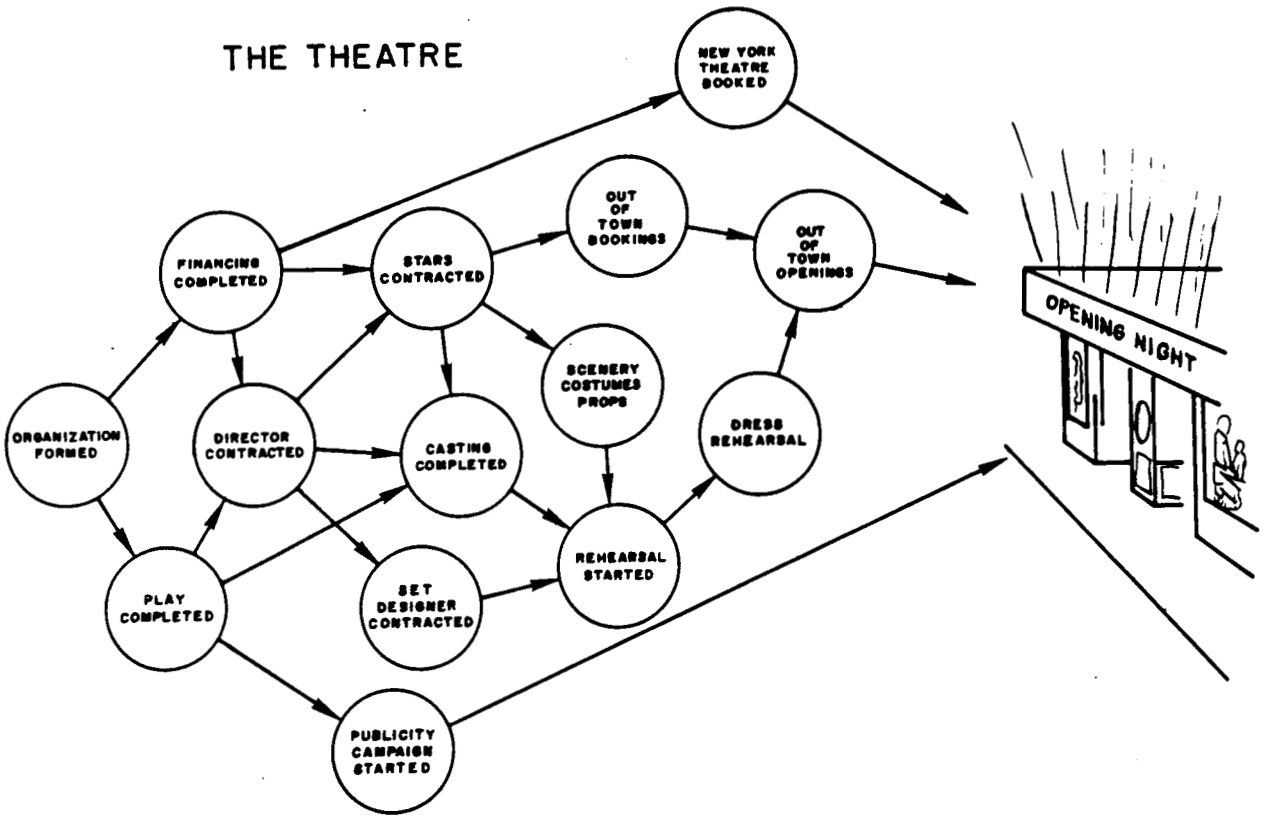


FIGURE I.2

PERT COST

MANAGEMENT SUMMARY REPORT

ABC DEVELOPMENT PROGRAM	REPORTING ORGN.	CONTRACT NO.	REPORT DATES
	MQZ CORP	98-7865	TERM (SPAN): TOTAL PROGRAM CUT OFF DATE: 31 MAR 63 RELEASE DATE: 10 APR 63
LEVEL/SUMMARY ITEM: 2/PILOT PLANT			

ITEM	COST OF WORK $ (000)						SCHEDULE		REMARKS
	WORK PERFORMED TO DATE			TOTALS AT COMPLETION			MOST CRIT SLACK (WKS)	COMPL DATE	S-SCHED COMPL DATE--TOTAL A-ACTUAL COMPL DATE-- ITEM E-EARLIEST COMPL DATE--CRITICAL L-LATEST COMPL DATE-- ITEM
	VALUE	ACTUAL COST	(OVERRUN) UNDERRUN	PLANNED COST	LATEST REVISED EST	PROJECTED (OVERRUN) UNDERRUN			P YR 1963 J F M A M J J A S O N D 1964 J F M A M J J A S O N D 5 6 7 8 L YR
LEV 2 PILOT PLANT 22,300	850	1,050	(.23) (200)	2,500	3,000	(.20) (500)	-8.6	30JUN65 13SEP63 15JUL63	SEE PROBLEM ANALYSIS RPT ITEMS 1-3
LEV 3 P. PLANT MAIN COLUMN 22.310	420	470	(.12) (50)	1,200	1,350	(.12) (150)	-6.3	1JAN65 20SEP64 6AUG64	ITEM 6
LEV 3 P. PLANT POWERPLANT 22,320	27	25	.07 2	350	350		-6.7	1JAN65 16FEB65 1JAN65	ITEMS 9-13
LEV 3 P. PLANT CONTROL BLDG. 22,330	190	201	(.06) (11)	225	260	(.16) (35)	-8.6	15JUL63 13SEP63 15JUL63	ITEM 15
								TIME NOW	

FIGURE I.3

PERT

MILESTONE REPORT

ABC DEVELOPMENT PROGRAM	REPORTING ORGN.	CONTRACT NO.	REPORT DATES
	MQZ CORP	98-7865	TERM (SPAN): TOTAL PROGRAM CUT OFF DATE: 31 MARCH 1963 RELEASE DATE: 10 APRIL 1963
LEVEL/SUMMARY ITEM: 2/PILOT PLANT			

MILESTONE DESCRIPTION	SLACK	DATE	SCHEDULE	REMARKS
			S-SCHED COMPL DATE E-EARLIEST COMPL DATE L-LATEST COMPL DATE A-ACTUAL COMPL DATE M-EARLIEST COMPL DATE AFTER MGMT ACTION P YR 1963 J F M A M J J A S O N D 1964 J F M A M J J A S O N D 65 66 67 68 L YR	
12000685 START POWERPLANT INSTALLATION	-8.4	4 MAR 63 27 APR 63 12 MAR 63	S E L	
12000687 JOD CONTROL BUILDING	-8.6	15 JUL 63 13 SEP 63 15 JUL 63 31 AUG 63	S E L M	
12001999 JOD ADMIN. BLDG NO. 1	2.2	31 DEC 63 15 DEC 63 31 DEC 63	S E L	
12002405 COMPLETE POWERPLANT INSTALLATION	-6.3	10 MAR 64 23 APR 64 10 MAR 64	S E L	
12004195 COMPLETE PHASE I CONTROL TESTS	-8.6	4 NOV 64 3 JAN 65 4 NOV 64	S L E	
12004280 COMPLETE POWERPLANT TESTS	-6.7	1 JAN 65 16 FEB 65 1 JAN 65	S E L	
12004291 COMPLETE MAIN COLUMN TESTS	-8.6	1 JAN 65 17 MAR 65 15 JAN 65	S E L	
12004310 PILOT PLANT OPERATIONAL	-8.6	30 JUN 65 29 AUG 65 30 JUN 65	S E L	
		TIME NOW		

FIGURE I.4

COST OF WORK REPORT

PROGRAM	REPORTING ORGN.	CONTRACT NO	REPORT DATE: 3/31/63
ABC	MQZ CORP	98-7865	TERM: PROGRAM
LEVEL/SUMMARY: 1/PILOT PLANT			CUT OFF DATE: 31 MAR 63 RELEASE DATE: 10 APR 63

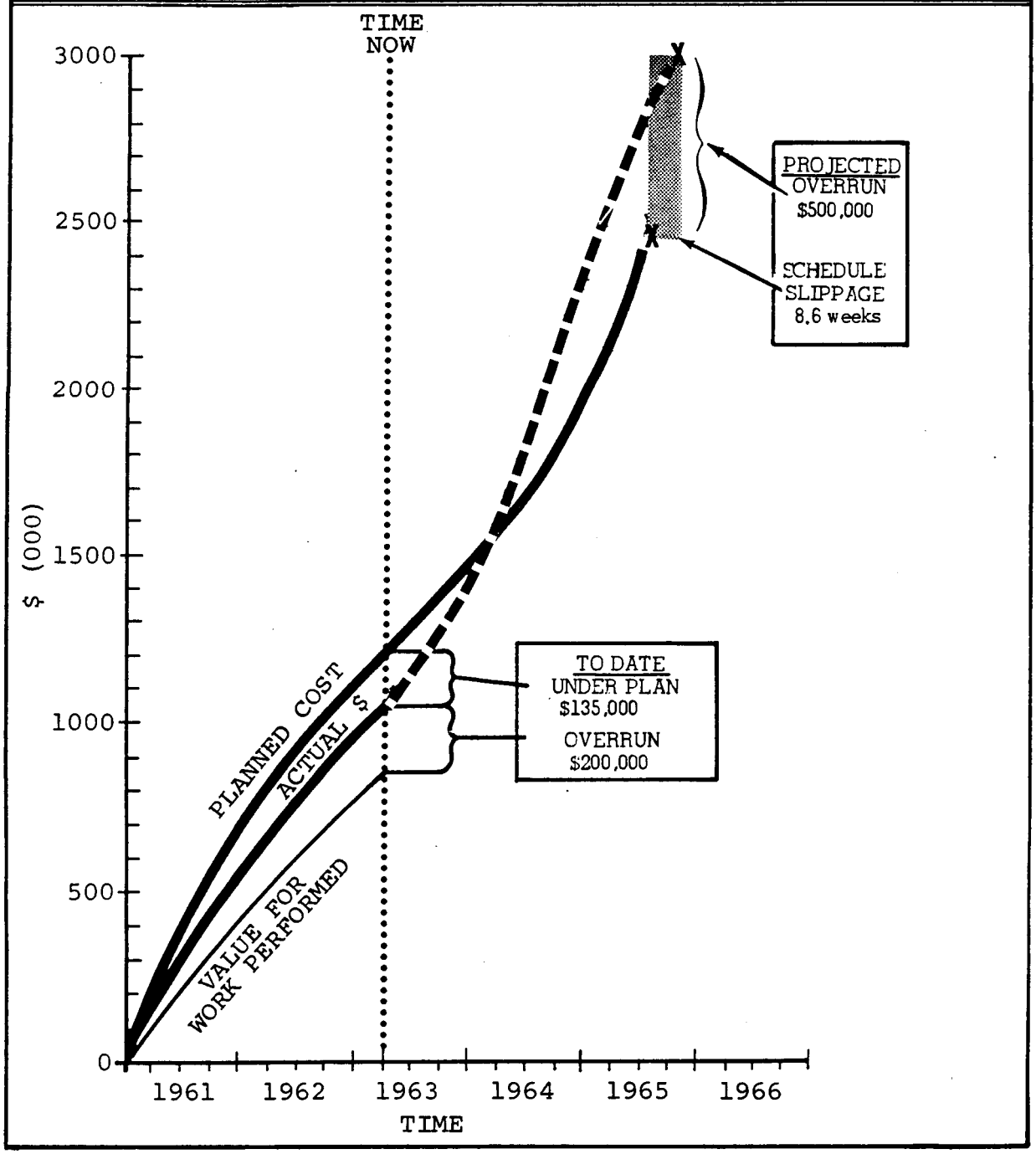


FIGURE I.5

PERT COST
COST OUTLOOK REPORT

PROGRAM	REPORTING ORGN.	CONTRACT NO.	REPORT DATES
ABC DEVELOPMENT PROGRAM	MQZ CORP.	98-7865	TERM (SPAN): TOTAL PROG. CUT OFF DATE: 31 MAR 63 RELEASE DATE: 10 APR 63
LEVEL/SUMMARY ITEM: 2/OPERATIONAL PILOT PLANT			

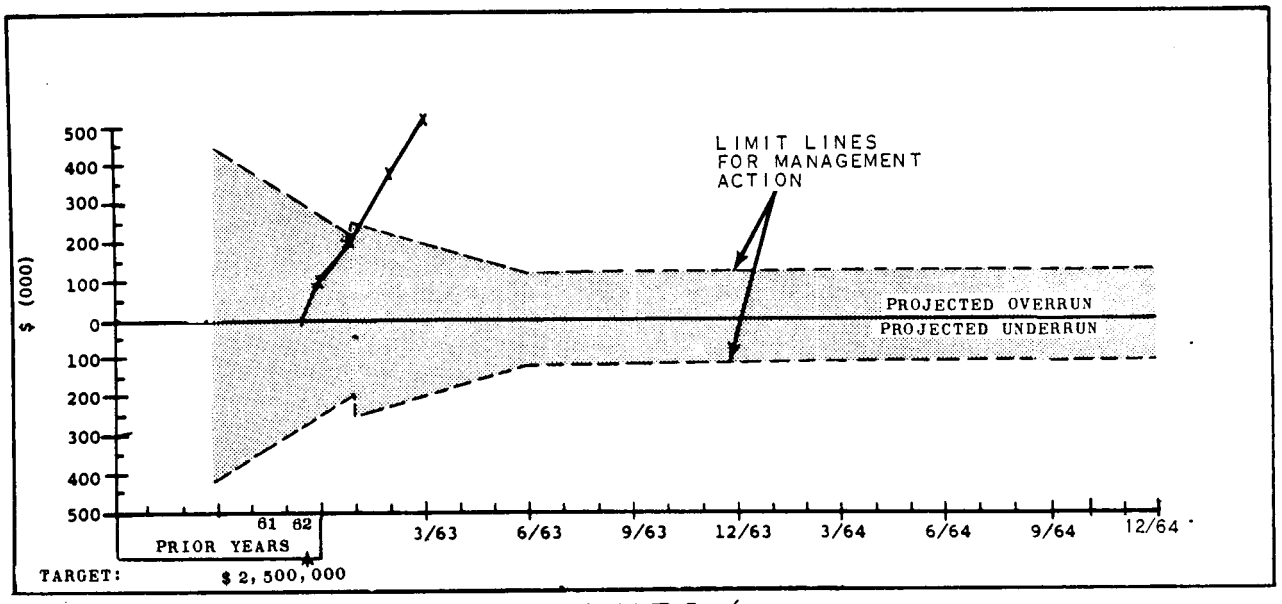


FIGURE I.6

PERT
SCHEDULE OUTLOOK REPORT

PROGRAM	REPORTING ORGN.	CONTRACT NO.	REPORT DATES
ABC DEVELOPMENT PROGRAM	MQZ CORP.	98-7865	TERM (SPAN): TOTAL PROG. CUT OFF DATE: 31 MAR 63 RELEASE DATE: 10 APR 63
LEVEL/SUMMARY ITEM: 2/OPERATIONAL PILOT PLANT			

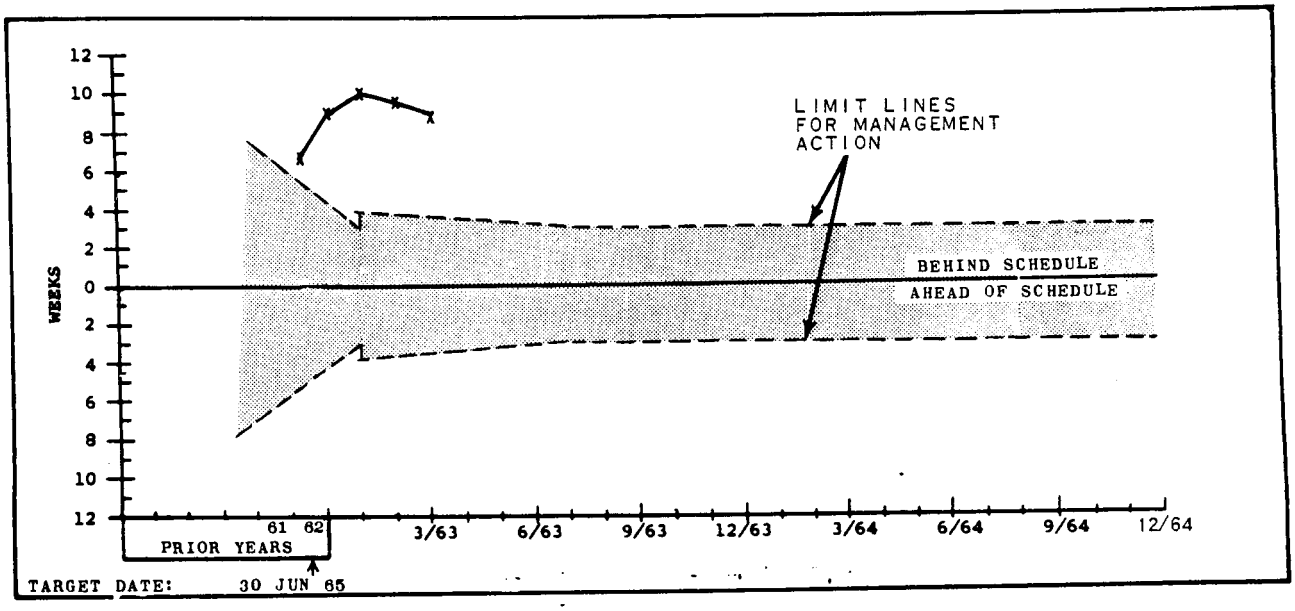


FIGURE I.7

Both government and industrial management benefit from the common use of PERT. It makes a team of the highest and lowest level of government agencies, field establishments, and industry by serving as a means of communication in all phases of the program. It is especially useful in construction projects, system development, production engineering, and few-of-a-kind production programs. When a high volume production program passes the production engineering or prototype production and test phase, other techniques may prove more appropriate. However, these must be compatible with an overall network management technique suitable for planning, scheduling and controlling the entire system from conception to operation.

Contractual arrangement, whether they are fixed price, cost plus fixed fee, or incentive variations of either, do not affect the applicability of PERT. The type of contract, however, may influence the emphasis placed on the use of PERT by either government or industry. For example, a contractor may elect to use PERT on a firm fixed price contract, even though its use may not be required by the contracting authority. Conversely, on a cost plus fixed fee contract, the government may be equally as concerned as the contractor with the use of PERT to control schedules and costs.

For the Manager - PERT:

- Measures accomplishment against current scheduled plans and objectives.
- Assists in identifying real time requirements and provides limits for detailed scheduling.
- Fixes responsibility and assures continuity of effort despite turnover in personnel, either executives or operating personnel.
- Provides disciplines which insure complete program coverage, avoids omission of important tasks at the outset of a program, and provides visibility from the total program objective down to the lowest supporting task.
- Spots potential future problem areas in time for preventive action or for improvement.
- Uses the management by exception principle in reporting to higher levels of management.
- Permits essential rescheduling and provides periodic evaluation of plans.
- Provides an opportunity for consideration of trade-offs in funds, manpower, performance, and time between critical and noncritical areas of effort as a means of improving schedule and cost situations for one or more programs.
- Makes it possible through its simulation techniques to evaluate and forecast outcome of alternate plans before implementation. Simulates and measures the effect of proposed changes in scheduled plans and permits an early identification of the most efficient plan when parallel approaches are used.
- Provides a historical data bank for the program which can be drawn upon for new programs.

ANNEX TO CHAPTER I
QUESTIONS AND ANSWERS

Q. Is PERT a new management system or process?

A. No. It is basically an improved technique for a more orderly approach to the management job. It provides a sound basis for planning, scheduling, and the ensuing continuous monitoring by successive levels of responsible management.

Q. What are the advantages of using PERT?

A. Some of the advantages of PERT are:

- It imposes a more rigid discipline for considering the various elements of effort required to achieve the desired objectives and the inter-relationships among the elements.
- It is a quick, effective method of communicating plans and their substance.
- It provides a structured plan which lends itself to a systematic determination of the total estimated required time, which can then be compared to a directed or desired completion date.
- It provides visible proof that a planning job has been done.
- It provides a means for appraising progress against approved plans and for forecasting problems in meeting a schedule.

Q. What will PERT do for me as a manager?

A. Nothing by itself. You will get a return, plus "interest", commensurate with what you have put into it. PERT is a new and effective planning tool for areas involving uncertainties. As a tool, its benefit is related to its understanding and use.

Q. Where can my organization go to get more specific detailed information relative to the application and operation of PERT?

A. This book is intended only as a guide. For detailed technical information as to application and requirements, contact appropriate government agencies or customers (i.e., NASA, Army, Navy, Air Force, FAA, AEC, prime contractors, etc.).

Q. Will it cost me more as a manager to use PERT?

A. This can only be answered by you depending on the scope and effectiveness of your present system. There may be a slight increase in cost, but the total cost should decrease as a result of more effective management. If intelligently used, it should increase the effectiveness of the planning, scheduling, and control function.

Q. Does PERT require a specialized form of organizational structure?

A. No.

Q. Is PERT done for or by the manager concerned?

A. A manager cannot delegate his responsibility for planning and evaluation. PERT does enable him to delegate to a staff some of the "work" associated with these basic functions under specific instructions. He still must retain the ability to visualize the composition of the program as it reflects the impact of or need for his "key" decisions.

Q. I have already used Line of Balance on production contracts. Why should I switch to PERT?

A. PERT has been developed as management techniques where uncertainities in time, cost and performance exist. Line of Balance has had the greatest use in quantity production involving repetitive type effort. The two techniques are not in conflict but complement each other.

Q. Will the Government require contractors to use PERT?

A. Many agencies will require PERT. In addition PERT network and data will be required in support of certain Requests for Proposals (RFP). Full PERT implementation will be required on many major programs. In addition, the use of PERT will be encouraged whenever it is applicable, as an effective management technique.

Q. Is it the Government's intent, through PERT, to direct operations internal to an industrial organization?

A. No. It is expected that industrial organizations will have established an effective management capability, pursue sound management practices, and make maximum use of the best available management aids, including PERT, thereby reducing the need for government direction.

Q. Reference has been made to the use of PERT and PERT Cost in proposals. Is this really practical considering the limited program definition in existence and the time available during the period of proposal preparation?

A. One of the primary advantages is that it will force better early definition of the program. The estimates of cost and degree of network detail will be limited by time and technical knowledge available at this stage.

Q. Can PERT be initiated after a program is underway?

A. Yes, assuming the program is of sufficient duration to derive benefit.

Q. What criteria will be applied in requiring the use of PERT by a given contractor, particularly small companies producing components or supplying materials?

A. PERT requirements will be a function of the magnitude and nature of the work being proposed or undertaken. Normally, small suppliers will not be required to apply PERT, but they may be required to furnish PERT input data to customers using PERT.

Q. Will small companies be required to have large staffs of PERT personnel?

A. No. Normally, a PERT requirement means only that the regular planning and control personnel have to develop a PERT capability.

Q. Are the government agencies going to help subcontractors down through the second and third tiers in the initiation of PERT?

A. Only to the extent necessary to insure that the agency's requirements will be satisfied. Normally, this responsibility will rest with the prime contractor.

Q. How can my employees get PERT training and who will pay for it when PERT is imposed by the customer?

A. PERT training courses are being offered by some government agencies to their respective contractors, and, in addition, courses are available from various commercial companies. Cost of PERT training, as with any managerial training in industry, is simply part of the cost of doing business.

Q. Is PERT responsive to contract changes?

A. Yes. PERT will accurately reflect the actual work plan through the recyclying process.

Q. What has experience indicated with respect to the reliability of telegraphic (TWX) transmission of PERT data?

A. Very good, if care is used in preparing the data for transmission. It is recommended that the receiving facility be equipped to copy in more than one way; e.g., printer and punched tape. The two copies can then be verified against each other.

Q. Can PERT be used without a computer?

A. Definitely. Networks containing 200 or even more activities can be processed in a matter of hours with the aid of simple calculating devices. However, the use of EDP equipment speeds data processing for larger networks.

Q. Can the PERT network be used as a display device for showing progress against plan?

A. Yes. However, most experienced users have developed more effective graphic devices for this purpose.

Q. What is the difference between PERT and PERT Cost?

A. PERT was introduced to reinforce the planning and subsequent progress evaluation functions with respect to time. PERT Cost is designed to provide a method for managing a scheduled program in terms of the time/cost relationship.

Q. Do I have to revise my entire accounting system to accommodate PERT Cost?

A. Experience to date indicates that PERT Cost is compatible with good contractor cost accounting systems. Many present cost accounting systems were developed for repetitive production and are based upon process or flow costing, while PERT Cost is essentially a "job shop" or "work order" type costing. However, the marriage of these two concepts of costing can be accomplished at the "work package" level set forth in the DOD and NASA PERT Cost Guide.

Q. How closely will contractors be required to follow the details of PERT Cost Guide?

A. Contractors will be required to adhere to the PERT Cost concepts expressed in the DOD and NASA PERT Cost Guide and implementation procedures issued by the contracting authorities. Minimum requirements for reporting to the Government with respect to format have been developed.

Q. Will the Government accept PERT Cost data on an accounting month basis; i.e., four, four and five week quarters? Will bi-weekly reporting, which is phased to match these periods, be acceptable?

A. Contracting agencies will be encouraged to allow their contractors to time the preparation of PERT Cost reports to be compatible with contractors' established accounting practices. At least one computer manufacturer, indicates its PERT Cost computer program has a capability of accommodating accounting periods other than calendar months as well as calendar months.

Q. If cost control is to be effective, it seems that cost subdivisions must be the responsibility of a specific individual. Is this realistic, considering PERT Cost end items may involve a number of organizational units?

A. In the final analysis, any responsibility must rest with a specific individual. This is recognized in PERT Cost in the requirement for identifying each work package with a "responsible unit" manager.

Q. Is it intended that the PERT Cost work breakdown structure correspond to "contract items"?

A. No. The contract items should correspond to upper levels of the product oriented work breakdown structure.

Q. For PERT and PERT Cost, is it absolutely necessary to obtain the time and cost estimates from operating personnel?

A. Yes. However, in some cases, experienced estimators may furnish good cost estimates, provided, the advice of such specialists is coordinated with the individuals directly responsible for accomplishing and controlling the work.

Q. How does "Companion Costing" differ from PERT Cost as set forth in the DOD and NASA Guide?

A. No difference in objectives. Companion Cost uses the same concepts of a work breakdown structure but the correlation of cost and time data takes place at higher summary levels. Also contractor reporting for Companion Cost requires different formats and content than for PERT Cost.

Q. We have been using CPM. Will this new PERT Guide mean that we have to change?

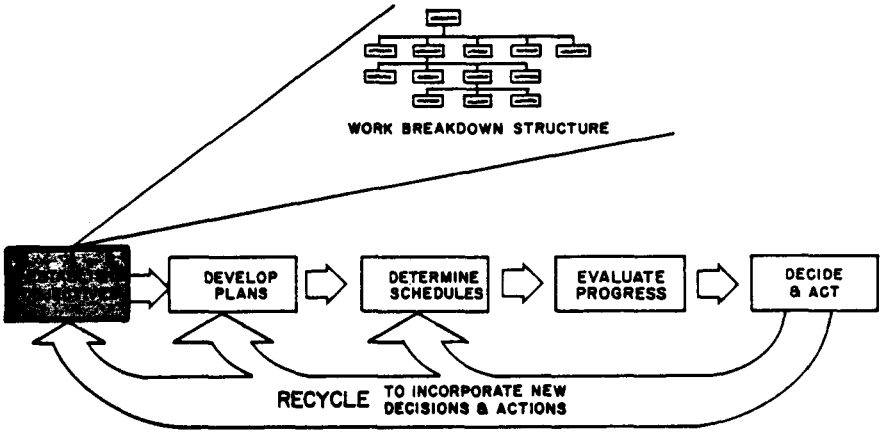
A. Any selected system will have to be flexible enough to generate data in the form required by the contracting authority.

Q. What about Defense Contractor's Planning Report (DCPR)?

A. The DCPR is a uniform program information system for collecting, storing, and analyzing pre-production, production, and sustaining data by contract, on aircraft, missile, and space systems. DCPR type data is intended for use in contract negotiations. It will provide decision makers and negotiators with data on actual quantitative experience similar to that which the contractor may have used in preparing the proposal. It will also provide comparable data, cost relationships, and benchmarks as an aid in performance monitoring by a central analysis group. DCPR may be used as a supplement to PERT Cost on large programs. DCPR collects summary data in a uniform manner.

CHAPTER II

IDENTIFICATION AND ORGANIZATION OF OBJECTIVES



Management may be defined as a process of identifying and organizing objectives, and planning and employing resources to accomplish them. An operating organization and its management provide means to accomplish an objective. The responsibilities of an operating manager are the organization and supervision of the work required to meet the objective.

The manager must be alert to opportunities to achieve the required objective with the efficient use of resources and time. The effectiveness of an operation is a measure of the manager's ability to attain the required objective within the quantity, quality, time, and cost goals established in the planning to reach the objective.

Identification and Definition of Objectives

The following steps are important before work to accomplish any program begins:

- the prime objectives must be carefully determined and defined;
- the supporting objectives leading to the attainment of each prime objective must be carefully determined and defined;
- the objectives must be organized and interrelated to enable attainment of overall program objectives;
- these objectives must be communicated effectively to operating management in the next lower levels of the organization.

Answers to the following questions will help to determine and define the prime and supporting objectives by working from the overall program objectives and downward in detail:

- What operational system (s) or end item(s) will this level of operational management and its units be responsible for producing?
- What are the major phases of work and significant objectives through which the operational system(s) must move to completion?
- How are these objectives related?

Each management level develops supporting objectives for the next level below. After defining the supporting objectives each level reviews them with the next higher level to assure consistency before final decision.

Communication of Objectives

The prime and supporting objectives must be communicated, in writing. This communication is the essential basis for plans, schedules, and later management operations. The following are minimal requirements:

- prime and supporting objectives must be determined and defined in sufficient number to provide the basis for outlining the step-by-step process by which the qualitative and quantitative objectives of the program are to be attained;
- the projected divisions of labor must be detailed among responsible organizations in the manner consistent with the objective of higher authority;
- relationships between supporting objectives and prime objectives must be indicated in order to obtain perspective on the attainment of integration in prime objectives.

Organization of Objectives

Objectives may relate to equipment, services, facilities, decisions, or data. In PERT, these objectives are organized and specified in terms of end items which are either deliverable or constitute a commitment from the organization. For example, the development of a system having certain specifications is the objective for the program shown in Figure II. 1. Since the program is complex, it has been subdivided into items (e. g., launch equipment, aerospace vehicle, trained personnel) at the first level. End objectives must then be defined for each of these items. Each first level item can be subdivided into other items defined at successively lower levels, as is shown in Figure II. 2 for the Aerospace Vehicle.

In order to assure integration, the objectives must be based on the total program first, and then extended downward to the more detailed level. Three reasons for this top-down approach are:

- it assures that the program objectives are fully supported by lower level objectives. Planning from the bottom up may not assure that complete coverage is obtained;
- it assures that the program structure is totally integrated and that each part of the program is consistent with and related to the program as a whole. Planning from the bottom up might allow the individual components to become ends unto themselves and be developed according to conflicting objectives;
- it helps assure that useful summaries of program information can be made. The selection of information, meaningful to successive higher levels of management, is difficult unless the data is summarized upward according to the structure lines of a top-down plan.

Work Breakdown Structure

A product-oriented work breakdown structure reflecting the organization of objectives is essential to any PERT installation. The structure is developed downward by proceeding from the definition of the program objectives through successive levels to the lowest level of detail required for effective program management.

This produces a graphic representation of the program structure and establishes a common framework for the accomplishment of all the work to be performed. It enables assignment of responsibilities, delineates objectives for monitoring progress, and provides a basis for uniform planning and program visibility.

This structure of the program thus identifies the major program end items (hardware, decisions, services, equipment, or facilities). The major end items are then divided into their component parts (e. g., systems, subsystems, components), and the component parts are further divided and subdivided into more detailed units.

Briefly the work breakdown structure establishes the basis for:

- defining the work to be performed in successively greater detail;
- determining how the various end items of work are related to the program objectives;
- identifying the organizational element(s) responsible for accomplishing the work at each successive level of work definition;
- summarizing actual status and forecasted progress of the program for progressively higher levels of management;
- constructing networks at any desired level of detail.

SIMPLIFIED EXAMPLE - WORK BREAKDOWN STRUCTURE, LEVEL 1

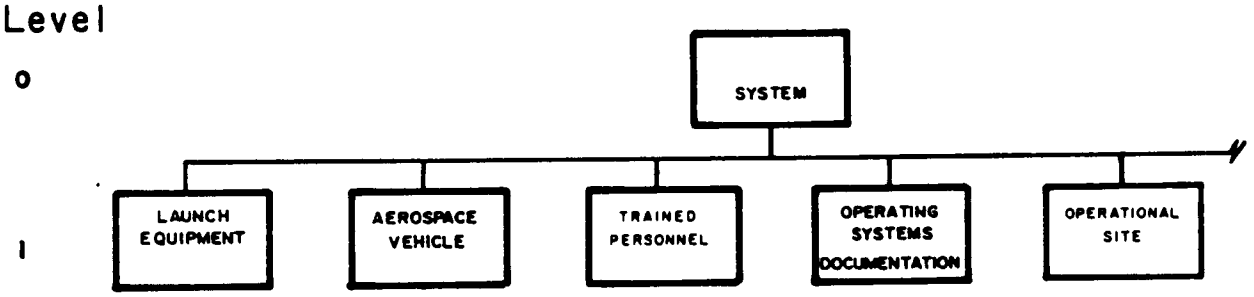


FIGURE II.1

SIMPLIFIED EXAMPLE - WORK BREAKDOWN STRUCTURE, LEVEL 2

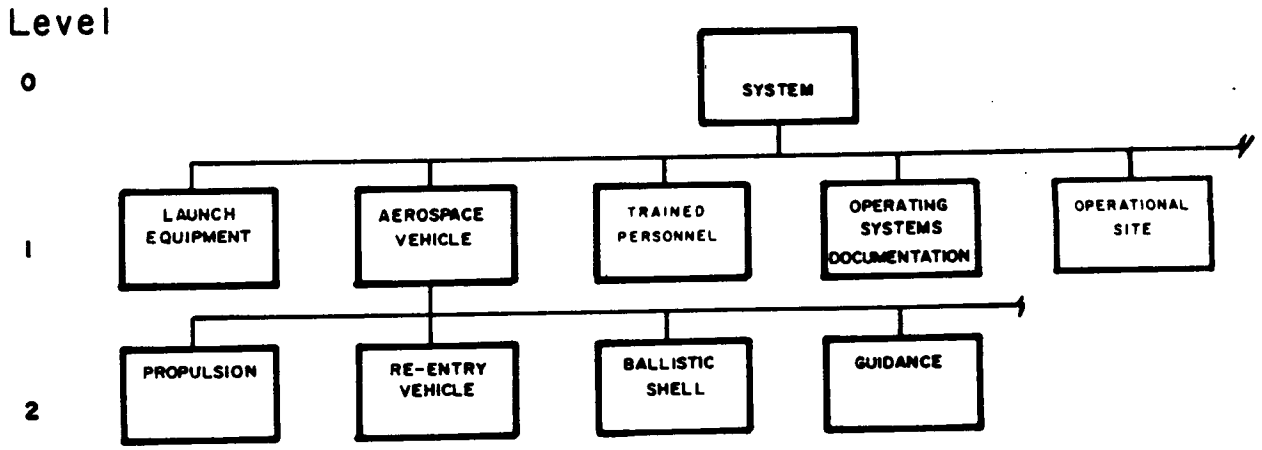


FIGURE II.2

A program is illustrated in Figure II. 3. The subdivision of the work breakdown structure is continued to successively lower levels, until it reaches that level where the item subdivisions finally become manageable units for planning and control purposes. 1/

Work Packages

The next logical subdivision for planning and control is a breakdown of each of the end item subdivisions into work packages. A work package is the unit of work required to complete a specific job such as a report, a test, a drawing, a piece of hardware, or a service, which is within the responsibility of one operating unit within an organization. It is represented on a PERT network by one or more activities as necessary to identify and control the effort. These activities will be assigned to corresponding operating units within the organization.

The configuration, content and detail of the specific work packages to be identified will vary and will depend upon:

- the status of the program;
- the size and complexity of the program;
- the structure of the participating organizations;
- the assignment of responsibility for the work, according to the judgement of the manager.

These considerations will also determine the number of end item subdivisions that will be created on the work breakdown structure before the work packages or activities are identified and responsibility for them is assigned to operating units. The amount of detail is a matter of judgement for joint consideration by the managers of the program.

Similarly, sections of the work breakdown structure may vary in the number of levels into which they are subdivided, even in different parts of the same program. For example, "Trained Personnel" may be subdivided only to four levels, whereas portions of "Aerospace Vehicle" extend to six or more levels.

As the work breakdown structure is defined, any interfaces between the various subdivisions on the structure should be identified and subsequently recorded as events on the appropriate network. Interfaces are defined as events which signal the transfer of responsibility, end items, or information from one part of the plan to another.

Figure II. 4 illustrates the relationship of program objectives through the work breakdown structure and work packages to networks.

The degree of detail required for planning and control during the execution phase of a program may be greater than that required for proposal preparation. This does not mean that the technique is applied in a different manner, but rather, that the work breakdown structure is developed initially only to the level of detail specified by agency policy as essential for proposal evaluation. The work breakdown structure is later extended after contract award into the lower levels of detail needed for effective planning and control of the work as it is performed.

Recycling

Discussion of the identification and organization of objectives is incomplete without consideration of the recycling process. 2/ Objectives may be changed by higher level authority, or they may have to be changed as a result of failures or successes in accomplishment at lower levels in the program. If change occurs, it may be necessary to recycle the processes which lead to the determination of some objectives.

1/ The use of the work breakdown structure is not intended as the frame of reference to establish the organizational structure of management.

2/ Chapter VI discusses the recycling process in detail.

SIMPLIFIED EXAMPLE- WORK BREAKDOWN SCHEDULE, LEVEL 4

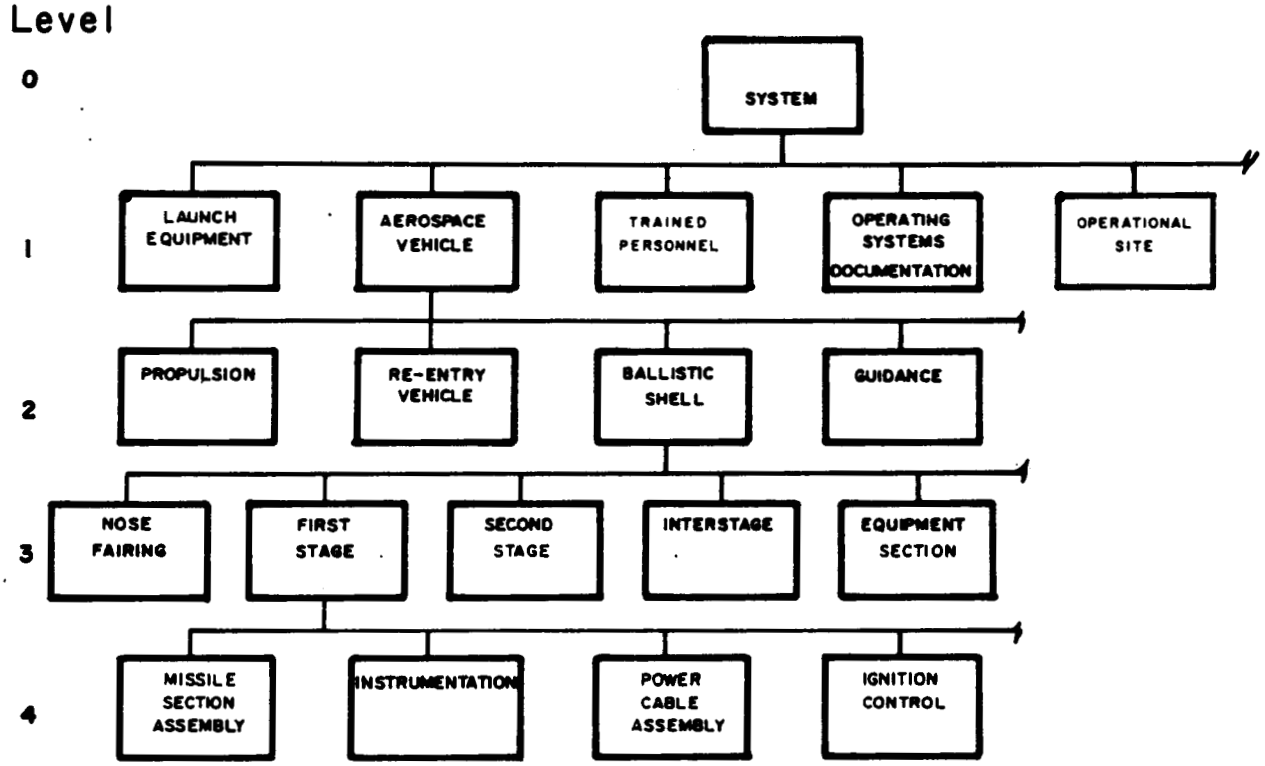
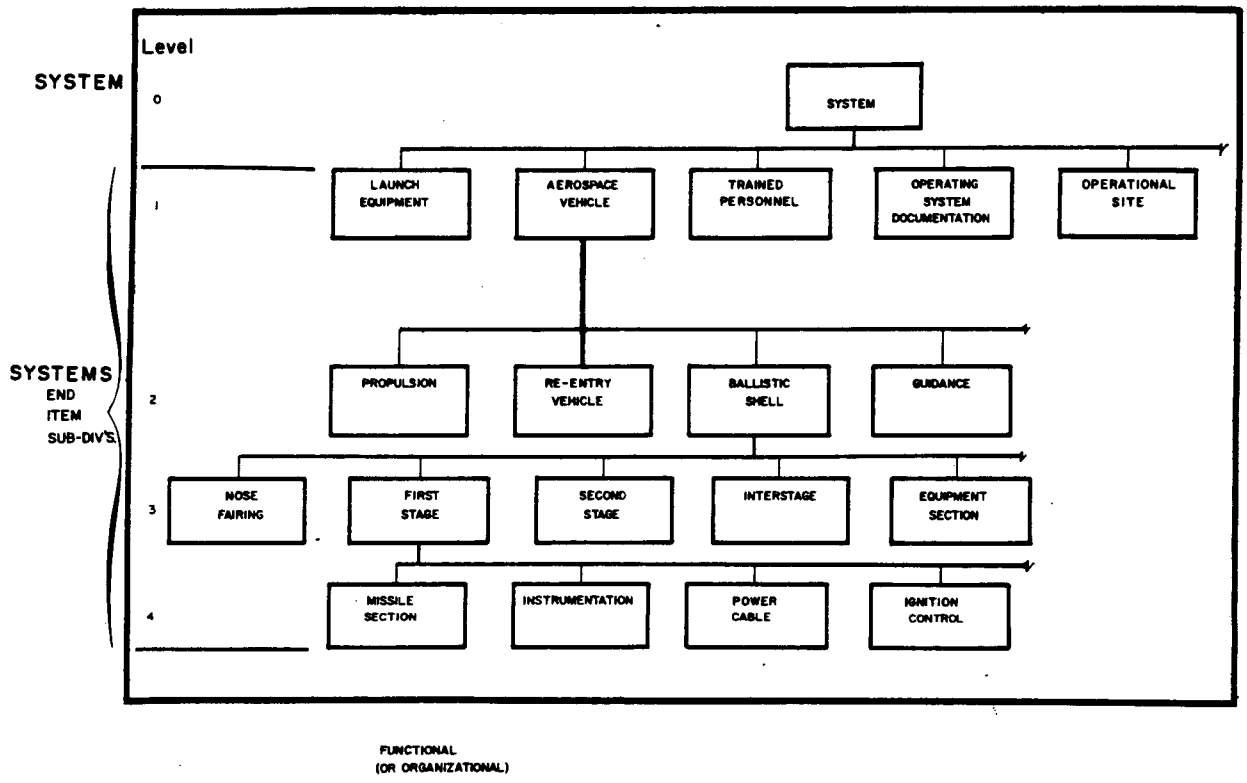


FIGURE II.3

SIMPLIFIED EXAMPLE - RELATIONSHIP OF SYSTEM WORK BREAKDOWN STRUCTURE THROUGH WORK PACKAGES TO NETWORKS



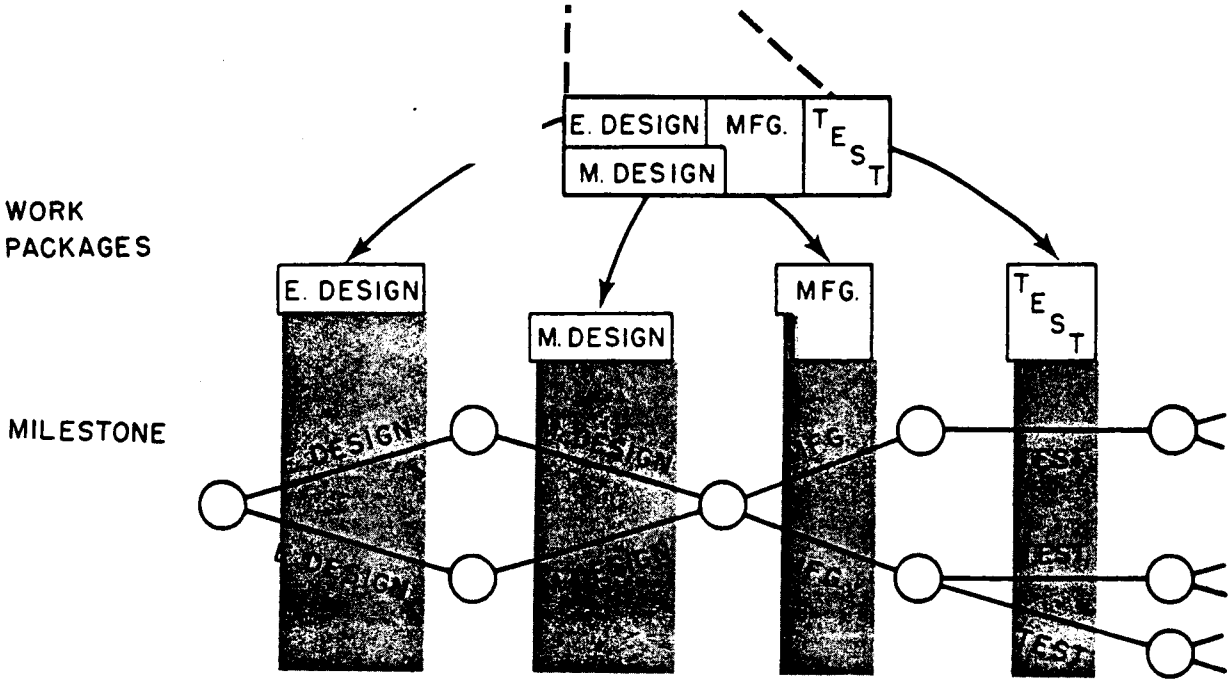
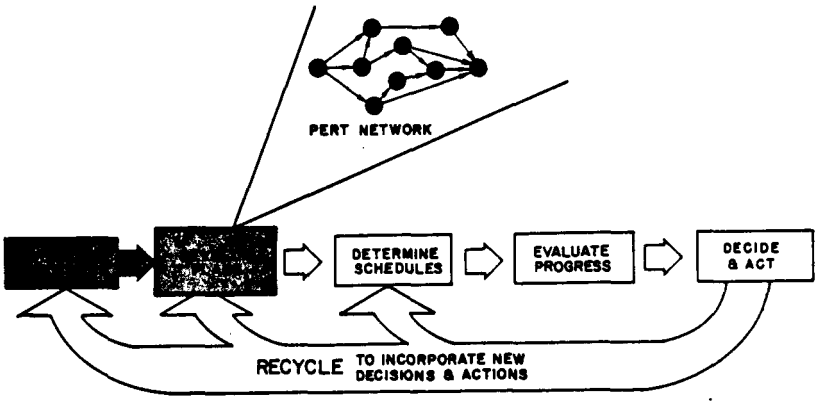


FIGURE II.4

CHAPTER III

PLANNING TO ATTAIN OBJECTIVES



A plan consists of documentation, preferably made before an operation begins, which delineates the various tasks required to achieve a predetermined objective. The manner and order in which these tasks are to be accomplished is indicated. The plan shows what task is expected of each component of the team organization. The plan is converted to a schedule when it is assigned to calendar periods or points of time in order to meet an objective date. The schedule dictates when this task must be started and completed. In PERT the function of planning is separated clearly from that of scheduling. When a plan is converted to a schedule a base is established against which to evaluate progress and to assess the impact of uncertainity in a program.

Once the program objectives are identified and translated into the work breakdown structure, a work plan for achieving each objective in the most desirable manner must be developed. Since not all activities can begin simultaneously, due to technical constraints and resource limitations, they must be put in logical sequence according to the desired relationships and interdependencies. They are shown in schematic form on the PERT network.

PERT Networks

The PERT network is a logic diagram or flow chart which identifies the interfaces, relationships, and constraints in the program.

The network is a graphic description of the plan showing the sequential steps needed to reach a stated objective (for example, the R&D, testing, tooling, establishment of a logistics system, etc., that are needed to make a system operational). The network must be comprehensive and include all significant interdependencies and interactions required to perform all the work packages in the program. However, judgement must be exercised to limit the level of detail to that which will best serve the objectives of management.

After the network plan has been developed, managers may use network information to assist in determining the current status, predicting future status, and replanning as required to meet current objectives.

Network Events

By PERT definition, an event is a specific definable achievement, either the beginning of or the completion of one or more activities. Events, as shown on Figure III. 1, are meaningful, specific accomplishments, either physical or intellectual, which do not consume time or resources but rather occur at points in time. Circles, squares, rectangles, or other geometric figures are used to represent events in the network.

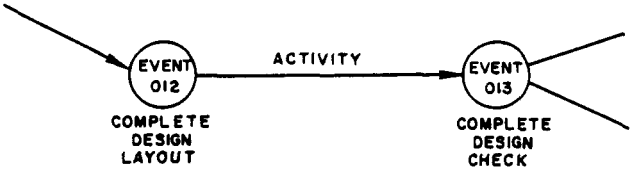


FIGURE III. 1

Events are the basis for status monitoring and often for partially describing the activities which lie between them. In many cases, they may be simply "Begin Activity X" or "Complete Activity X". In other cases, they may represent the accomplishment or beginning of a significant phase of the total job, or the transfer of responsibility from one organization to another. Often they may be points of decision, where alternatives are eliminated or chosen. In addition, events often indicate the completion or initiation of several activities.

Care must be exercised that an event is clearly defined and therefore meaningful. For instance, the event might be "systems budget estimates completed," and the evidence would be the release of the document by the responsible office. In order to be assured that the event is truly defined, it is desirable to specify the evidence of accomplishment and the reporting office when initially describing the event.

Network Activities

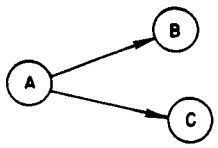
An activity is a task or job to be done, characterized by persons using resources for some period of time in order to accomplish a stated objective. Such an activity might be preparing, researching, building, negotiating, deciding, testing, or other similar actions. Activities are the channels for the vital "flow" of the network, and it is this vital flow of human effort, use of materials and facilities, investment, expenses, and progress toward a timed objective that is controlled by the manager.

An activity is represented on a PERT network by an arrow which links two successive events, as shown in Figure III. 1. An activity, normally time consuming, may simply represent a connection or interdependency between two events on the network.

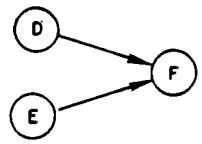
The rules of logic for the PERT network require that activities be clearly defined. They must be able to take place independently of each other and must not require inputs other than those shown by the network as feeding into the initiating event. Further, the activities in a series with each other must also be independent; that is, the time which one takes should not affect the time which any of the following take. Networks are based on the assumption that an activity cannot be started until its preceding event has occurred. The event succeeding an activity cannot occur until all activities leading to the event are accomplished.

Network Contraints

These activities and event relationships are termed contraints as illustrated in Figure III. 2.



Event A constrains Activities A-B and A-C.



Activities D-F and E-F constrain Event F.

FIGURE III. 2

In some instances, there is no specific activity required between two events connected by a constraint line, and the result may be a "zero-time" activity. Such constraint relations may be used to tie the completion of several activities to the beginning of a single activity, or vice versa. Constraint may also be used when it is desirable to indicate by separate events the ending of one activity and the beginning of the following one. This may be desirable in cases where the completion of one activity is of major significance and where it is necessary to assure that the following activity begins immediately as planned. Figure III. 3 illustrates a zero-time activity between two events to show the completion of one activity and the beginning of another activity.

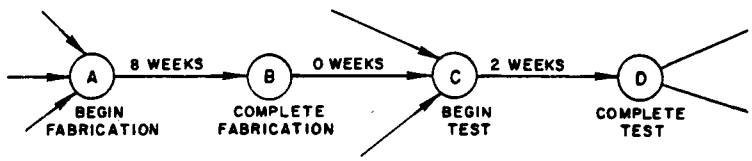


FIGURE III. 3

Interrelated Networks

In most large programs it will be desirable to prepare a number of separate networks describing individual segments of a program and delineating the detailed plan of work in these areas. In all programs it is essential, however, to develop a work breakdown structure which establishes the basis for all of the supporting networks and interrelates these networks.

Interface events must be identified before the networks are completed and provided for at each level, working from the top to the bottom. An interface event is an event common to more than one network. Examples of interface events are the receipt of an item (hardware, drawing, specification), or the release of engineering drawings to manufacturing. Figure III. 4 is a simplified example of interfaces between networks. In this example, Event 168 is constrained by an event on another network (No. 1) while Event 177 is constraining an event on still another network (No. 3). In some programs it is useful to maintain a special network for the program as a whole which shows only the interface events. In more complex programs in which the number of interface events is too large to show on an interface network, it has been found helpful to use computers to maintain interface data. Records of such detail as interface event dates, subject matter and responsible parties can be read out periodically for action as necessary.

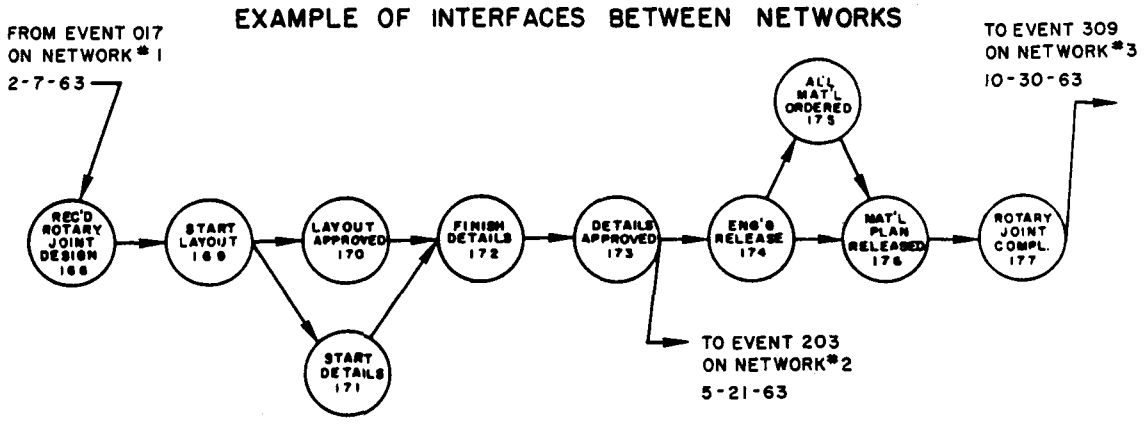


FIGURE III.4

Detailing of Work Packages

Prior to forming networks of activities and events, the work must be broken into work packages. This division of work may take the form of detailed organizational or functional identification, such as electrical design or mechanical design, or it may take the form of a more detailed end item identification within design, such as instrumentation design, power cable design, missile section assembly, etc. The breakdown chosen for more detailed identification will depend, again, on the structure of the performing organization and the manager's judgement as to the way he wishes to assign responsibility for the work. The amount of detail needed by a manager to plan and control his work will naturally govern the number of these smaller subdivisions.

Assume, for example, that the end item subdivisions "First Stage Instrumentation", appearing on the lowest level of the simplified work breakdown structure shown in Figure III. 5, requires design, manufacturing, and testing work. Because of the contractor's organization structure and the complexity of the work to be performed, however, the design work is further divided into two smaller divisions of work (electrical design and mechanical design) for assignment of responsibility. The manufacturing and testing work, on the other hand, are each treated as separate work units, since responsibility for the manufacturing and testing effort rests with a single unit in the contractor's organization, and it is unnecessary to divide this work into smaller work packages for planning and control.

In this example, the four work packages or activities (electrical design, mechanical design, manufacturing, and testing), as identified in the end item subdivision "Instrumentation", constitute the basic units for planning and control.

As preparation for construction of a network, the following categories of information should first be identified and listed for reference:

- the prime and supporting objectives;
- the work packages to be performed;
- all known events and interfaces for each separate work package;
- all known activities for each separate work package; and
- the offices responsible for the events and activities.

SIMPLIFIED EXAMPLE — WORK PACKAGES

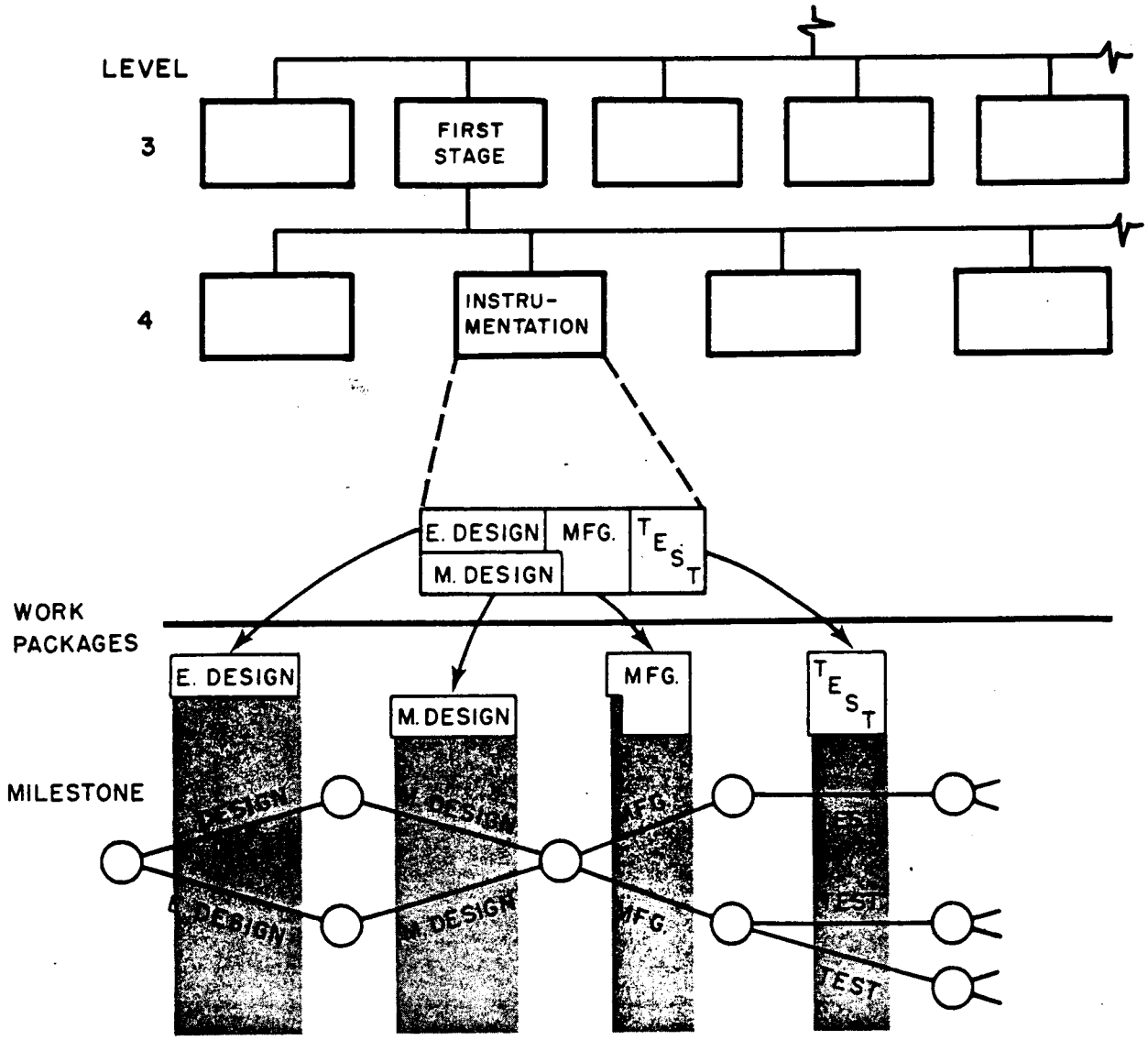


FIGURE III . 5

As will be seen later the same procedure is followed for the development of PERT Cost.

Procedures

Experience has shown that there are advantages in constructing a PERT network by starting with the end objective of the program and proceeding backward to the beginning event. Since the end objective is constantly and clearly in view, plan may be developed in direct relation to it. In constructing the network, certain other mechanical procedures should be carefully observed:

- all activity paths must be completed. Activities may never represent alternative paths from one event to another, but mandatory tasks that have to be accomplished before the succeeding event can occur;
- an event cannot occur until every activity preceding it has been completed;
- an activity succeeding an event cannot be started until the event has occurred;
- an event cannot occur twice, nor supersede itself; i.e., a path of activities may not form a loop that returns to any event;
- only one activity or constraint line may connect any pair of events.

Event and Activity Definition

Precise event identification and definition are necessary to properly determine event occurrence which indicates the actual progress made in the program. Correct activity identification and definition are equally important so that the best possible time and resource estimates can be obtained. It is good practice to define explicitly each activity and each event while the network is being developed and to list the responsible office and the evidence of activity completion.

Network Responsibilities

The network must be developed and maintained as a valid depiction of the program plan, suitable for use in the actual management of the program. If the network does not accurately represent the program, serious errors may result. In making the network plan valid, the manager himself must undoubtedly become involved.

The development of the PERT network is inseparable from the function of planning as understood by management. Perhaps the single most significant statement to be made regarding the development and maintenance of the PERT network is that it must be created by personnel in the manager's organization who are normally responsible to him for performance of the program planning function. Until these planners become skilled in the development, use, and maintenance of PERT, they may require the assistance of PERT specialists in the creation of new or revised networks. All participants must have a common understanding of the objectives to be reached.

If responsibilities are clearly assigned to these personnel, the network will be more complete and accurate than plans prepared in other forms and formats. Program planning personnel must plan in detail to effect the development and maintenance of the program plan in the form of PERT networks.

The development and maintenance of the network materially improves performance of the planning function. This function on a large, complex program, is demanding. The logical and systematic thought processes required of planners in the construction of the PERT network, inevitably deepens understanding of the objectives of a project and of the work to be performed.

Time Estimating and Network Calculations

Concepts and Principles. The estimated time required to perform each activity in the network is based on the following:

- planned manpower or other resources;
- average resource application rates or work schedules (the 40-hour week, the number of shifts, etc.).

This time value should not initially be considered in terms of calendar date, but rather as flow time. Any identification with preset calendar dates is to be avoided, for it nullifies one of the major advantages of the use of the network.

Time estimates should be made by personnel most familiar with individual activities. The quality of the time estimates will depend on their background and understanding of the work to be performed as well as the capability of the interviewers who are collecting the data.

Time estimates are normally given in weeks and tenths of weeks, but depending on the program, other time units (e.g., days or months) may be used. For the majority of applications, however, the week is commonly used.

Each estimate should be based on all known factors affecting completion of the activity under normal conditions. As the program progresses, the estimates should be reviewed periodically and adjusted for changing conditions.

Expected Elapsed Time (t_e) 1/

The expected elapsed time (t_e) is obtained as follows:

- make a time estimate for each activity in the network;

- either a single time estimate or a range of estimates may be made.

If a range of estimates is considered necessary usually three time estimates are obtained for each activity; an optimistic, a most likely, and a pessimistic time estimate. These three time estimates indicate the degree of uncertainty in completion of the activity. A statistically expected time for each activity is then derived from the three time estimates.

When a single time estimate is given for an activity, it is used in all subsequent calculations in the same manner as the expected elapsed time (t_e) calculated from the three time estimates. In subsequent discussion then, t_e can be construed either as a single time estimate or as though derived from three time estimates. Time estimates must be as accurate as possible, since all other calculations depend upon them.

Activities of high uncertainty should be identified for the benefit of all users of the data such as schedulers.

Earliest Expected Date (T_E) 1/

After determining the expected elapsed time for each activity, these expected times are then accumulated from the start through the completion of the various network paths. In this way the earliest expected time for each event in the paths and total elapsed time for each path is determined. The earliest expected date for program completion is identified by the T_E for the final event of the network.

Latest allowable dates are then determined for each event in the network starting with a predetermined date for the end event and subtracting the expected elapsed time estimates, moving backward through the various network paths. The T_L (latest allowable date) for the first event of the network will then indicate the latest date by which the program can be started without causing the end event to slip beyond the predetermined target date.

Slack and Critical Paths 2/

The longest time path is called the critical path.

After both the expected date (T_E) and the latest allowable date (T_L) have been computed for each of the events, slack may be determined for each path in the network. Slack is the time difference between the expected date and the latest allowable date: Slack = $T_L - T_E$.

The amount of time the expected date can slip before it equals the latest allowable date (T_L) can also be used as the definition of slack. Slack can be either positive, negative, or zero. When the latest allowable date (T_L) is later than the expected date (T_E), positive slack exists. Positive slack is time to spare.

1/ See Glossary
2/ A more complete discussion of these concepts and their use may be found in Appendix B.

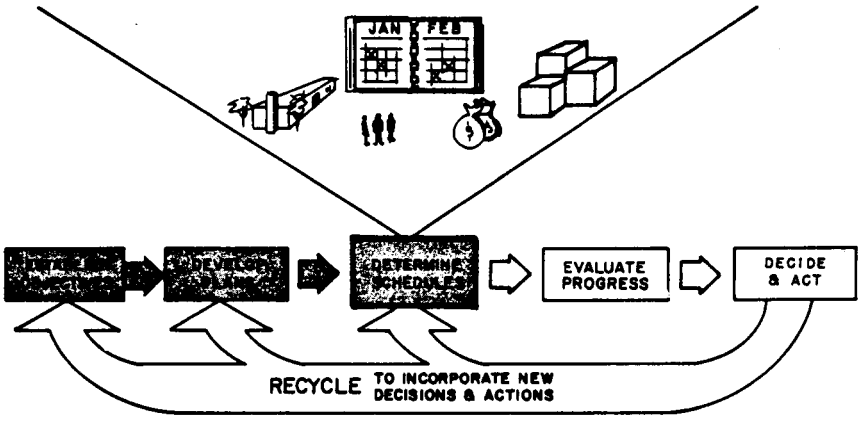
Directed Date Constraints

Frequently a directed completion date (T_D) for the entire program is established by government or industry. In many cases this directed completion date may be earlier in time than the expected completion date (T_E) for the initial planning networks. Under these circumstances, the total time required by the network plans must be reduced, if possible, to equal or be less than the directed completion date. Possible ways of shortening the planned time for the programs are:

- alteration of the network by introducing greater concurrency of effort;
- load resources on limiting activities;
- change the scope of activities;
- change performance requirements;
- balance the plan by reallocating resources among activities.

CHAPTER IV

SCHEDULING TO ACHIEVE OBJECTIVES



Scheduling may be defined as the translation of a plan into a timetable with specific calendar dates, which will govern the start and completion of work and authorize the expenditure of resources on each activity in the plan. The scheduled plan, when approved by responsible management:

- alerts lower level organizations and authorizes the use of resources including money and time;
- permits continuous comparative analysis of scheduled plan versus actual accomplishment, thereby enabling measurement and evaluation of status and forecast of progress.

The goal of the scheduling function is to bring into being an approved authoritative scheduled plan. Scheduling requires a high degree of skill and knowledge of the requirements of the activities to be accomplished and the capacities available. Scheduling is the function by which resources required by several programs or projects are established and managed as opposed to the functions of individual program managers. The balancing of these multiple and competing requirements for resources is a responsibility of top local management. This Guide emphasizes the importance of this function as discrete and integral parts of the management process.

Emphasis is placed on the scheduled start date as well as on the scheduled completion date for a planned activity. This is to:

- alert and authorize the responsible organization to get ready to start the effort;
- establish the earliest possible date to detect a significant deviation from plan;
- verify the completion of activities or relief of constraints.

Nature of the Scheduling Function

An approved plan is translated into a schedule by assigning resources and facilities to accomplish the planned tasks during specific calendar time periods. A major constraint in scheduling is the requirement to conform to the plan. If the start and completion date, for the planned effort and its desired completion date are scheduled using the same amount of elapsed time as the plan, the critical path becomes a demanding priority requirement. In the scheduling process a manager and scheduler must consider:

- the availability of the required manpower, equipment, facilities during specific calendar time periods;
- general sequencing of the work;
- consideration of resource requirements of other present or future programs;
- consideration of differing or conflicting demands on the same resources;

- preclusion of peak loads for particular skills or resources;
- adequacy of available local capacity and it augmentation potential vs. the "buy" instead of the "make";
- funding limitations;
- the minimization of premium costs and idle time for manpower, equipment, and facilities;
- the necessary integration through scheduling of several plans using the same resources;
- the manager's judgement of a reasonable time for performing the work under existing constraints;
- technical constraints in the form of uncertainities in activities which may require the provision of extra time.
- the local procedure for the development and communication of work authorization;
- local management policy with respect to work practices (i.e., single vs. multiple shifts, union contract provisions, vacation policy, etc.);
- laws governing work practices;
- difficulties involved in scheduling the detailed contents of the work packages far in advance;
- varying number of work days per month and translation to calendar dates.

All these considerations bear significantly on the problem of scheduling. Each must be weighed and balanced against other off-setting considerations.

Methods vary widely for converting time estimates for activities into specific calendar dates for starting and completing the work. For example, large packages of work may first be blocked into so-called master schedules to be used as a control in further scheduling. Each activity in a large work package may then be scheduled until ultimately the entire work package is scheduled. Conversely each activity may first be scheduled as a single unit.

Schedule formats will also vary. However, regardless of the method used for developing and communicating schedules, they become authorizations for performing the work only with management approval of their reasonableness for accomplishing the entire plan within the directed date. This approval requires a management appraisal of the risks involved in the various parts of the program and the advisability of reserving time and possibly resources for unanticipated problem areas.

This Guide recognizes the importance of the scheduling function to achieve objectives as separate and discrete from the function of planning to achieve objectives.

The interdependence between planning and scheduling must be maintained through the life of the planned effort. Any tendency to disturb the logical relations between these two functions should be avoided. Principles involved in this relationship include:

- the approved plan must govern the sequence and content of work to be performed;
- the schedule must validate the plan by converting it to a feasible timetable which can be approved by management. If the schedule cannot for any reason validate the plan, appropriate changes must be made to the plan;
- the schedule will not change the planned sequence of work. It will, with the approval of management, set the timetable which will actually govern the start and completion of work and resource expenditures required by specific activities in the plan;
- scheduling and planning must be so performed and continuously related that there is in effect at any one time only one scheduled plan for a given program approved by management.

Scheduled Dates vs Directed Dates

Some confusion has historically been generated by an indiscriminate use of the words "scheduled dates" or "directed dates". When a higher level passes objectives on to a lower level for planning purposes, these objectives are often accompanied by a "directed" date. It is not to be confused with "scheduled" date, although they may coincide. If, the "directed" date cannot be met, the scheduling activity must notify the planning activity so that higher level planning can be adjusted. The scheduler does not alter the plan.

Relationship of PERT to Scheduling

An important function of scheduling involves validation of the plan depicted by PERT networks. Calculation of the total elapsed time for accomplishment of the entire plan also provides other useful information. These calculations were made on the basis of estimated elapsed times associated with individual activities, which considered technical uncertainties and assumed availability of normal resource requirements. They were not based on elapsed time which would be consumed, following scheduling, in the actual performance of the work. The time period for completion of each of the activities in the network is of particular use in scheduling because of the technical constraints present in the plan.

Given unlimited resources, the "expected elapsed times" and the "expected dates", derived in planning, could be automatically used as the schedule. It is unlikely that this situation will occur. The calculations using individual elapsed time values do not automatically produce a realistic schedule for the individual activities in the plan. The scheduling process may require a change in the configuration of the networks to enable the effort to be performed with the specific resources available.

Some users of PERT have, in error, tended to take mechanical and automatic steps to arrive at program schedules by:

- keying the calendar start date of the program to the initial event or activity;
- "crashing" all activities into minimum possible times and relying completely on slack time as a measure of effectiveness or need for additional resources;
- scheduling only completion dates for activities and ignoring start dates.

These steps fail to consider the conflicting need for resources. Scheduling considerations are so interdependent that such steps as a substitute for judgement must be avoided.

Expected Elapsed Time vs Scheduled Elapsed Time

The process of estimating expected elapsed time must be clearly separated from the process of scheduling. The scheduled elapsed time (t_s) may be shorter, the same as, or even longer than the expected elapsed time (t_e) determined in the planning process.

In scheduling, an earliest completion date 1/ (S_E) and a latest completion date 1/ (S_L) for each activity in the network must be calculated in the same manner as the earliest expected date and the latest allowable date. The only difference is that scheduled elapsed time (t_s) values for network activities which have been scheduled are used in the calculation. Subsequent to establishment of initial schedule, these calculations should be made available to the schedulers on a routine basis.

Validating the Plan Through Scheduling

Greatly improved use of scheduling in major programs is needed. As a minimum, when PERT Cost is used, scheduling should always be accomplished to the work package level.

Practical problems in some organizations may prevent establishing schedules for individual activities below the work package level. When a program is of long duration it may not be possible to commit resources in detail to specific time periods through an entire plan. Where either situation prevails, expected elapsed time values should be processed as scheduled elapsed time values until scheduling is actually accomplished.

Validation of the plan should involve the following:

- analysis of the network and associated expected elapsed time estimates;
- study of the individual activity and path slack values;

1/ See Glossary of Terms

- study of "earliest expected" and "latest allowable" dates for events and the related periods of time in which calculations indicate activities should start and complete;
- decisions to schedule specific activities:
  a. according to the earliest expected dates,
  b. between the earliest expected and latest allowable dates, or
  c. earlier or later than either of these;
- validation or change of the elapsed time estimates produced during planning;
- subsequent study of any revision in the networks and accompanying data, occasioned by changes;
- coordination with other appropriate personnel organizations.

Study of Slack Values Based on Expected Elapsed Time

The slack time values for individual activities and paths through the network indicate a latitude of time within which the activities or the paths should start or complete.

The "latitude" or "cushion" may be used as a vital resource. Whenever the activities being scheduled are on a slack path the scheduler can use this slack time to adjust the demands of other planned activities to stay within the constraints of the time availability of capacities required. This point is stressed even though slack values are based on elapsed time estimates. In refining earliest expected date to the scheduled date for start or completion for an individual activity or path the scheduler must understand the slack values in areas of the plan before taking action to schedule.

Slack values may be found in any plan. If not present at the start of work, they invariably develop as the program progresses. The action of the scheduler in distributing the slack value inherent in a given path in no way violates or changes the plan itself. Other work in process in the same organization may preclude the application of slack which requires a change in resource application. Such situations may be resolved only by high level management.

Study of PERT Dates for Events and Activities

Both slack values and the actual PERT calculated calendar dates are of significance to schedulers. Schedulers should completely understand these dates and how they were derived in planning before scheduling actually begins. These dates facilitate any necessary coordination with planning in adjusting the plan to feasible schedules.

Decision on Start and Completion Dates for Planned Activities

The network and associated Output Reports comprise the frame of reference against which all scheduling constraints must be studied. In order to make decisions on start and completion dates for planned activities, the scheduler must consider the plan in relation to each of the contraints outlined under the section on "Nature of the Scheduling Function". Effective use of PERT should tend to make these decisions occur earlier and for more detailed activities, particularly in development programs. These decisions must be reflected in the PERT networks and data.

Validation or Change of PERT Networks and Data

As a result of scheduling, changes in the plan will result. Changes to the network or plan is the responsibility of planning, but once the schedule has been established, scheduling must feed back the necessary input data for revision of plan.

Entries into appropriate PERT input forms by the scheduling organization or other designated personnel subsequent to schedule decisions, will provide the necessary basis for changes in PERT records. Before these decisions are placed in PERT master data processing file, and prior to any promulgation of the newly developed schedules as the official schedule, a special "simulation" run of this input data, in conjunction with appropriate data in the master file, should be made. The impact of the newly developed schedule on the plan can be assessed by both scheduling and planning personnel prior to its official adoption. A graphic illustration of this process, when a computer is used, is depicted in Figure IV. 1. If more than one cycle of simulation is required, this can be continued until the schedule is consistent with management requirements.

Study of Revised PERT Networks and Data

At the time the schedule for individual activities and events is initially established, the expected completion date may be the same as the scheduled completion date. Once the program is underway and changes occur, the calculated earliest completion date may move ahead or behind the assigned scheduled completion date for an activity. Since this calculated date is likely to change frequently as the program continues, it would be impractical to change the schedules every time there is a change in the earliest completion date for an activity. Rather

SIMULATION OF PROPOSED PROGRAM CHANGES

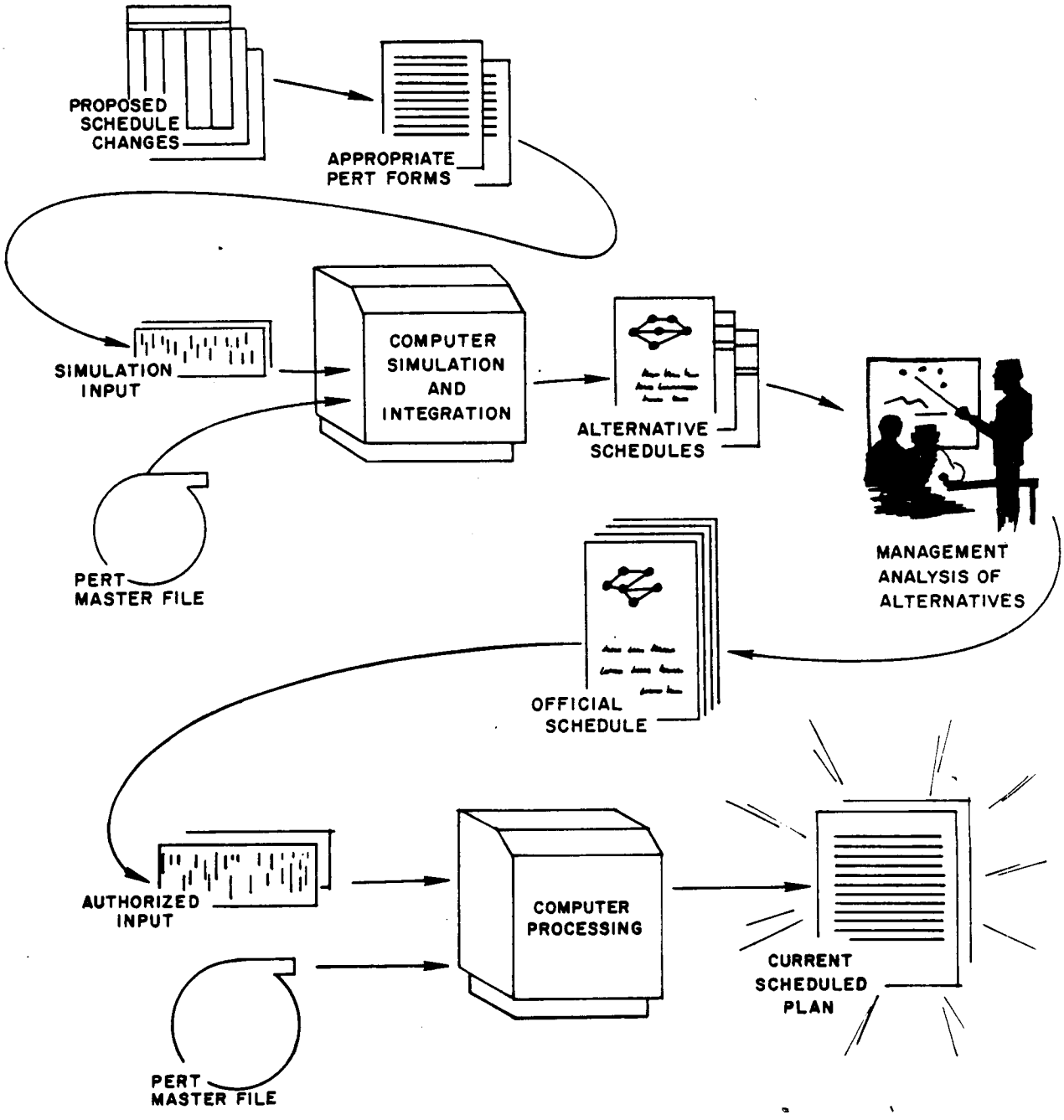


FIGURE IV .1

changes in this date should serve as one indicator for a scheduler in re-appraising his schedule and resource requirements. When this date deviates consistently, necessary adjustments in the schedule should be made.

Following scheduling of particular activities in the program and the introduction into PERT master files of scheduled elapsed time or scheduled completion dates to replace expected elapsed time (t_e) for these scheduled activities, slack values for these activities and paths containing them are automatically calculated by the computer and printed. Scheduled elapsed time values and expected elapsed time values for those parts of the plan not yet scheduled, are merged in slack path calculation. Positive slack as originally used to signal automatically the presence of excessive resources must be reviewed with reserve after scheduling of activities on segments of paths has occurred. Accordingly, managers should use this as only one indicator in accomplishing schedule revisions to offset negative slack conditions. There should also be an awareness that critical areas of the program may regularly be found in areas of the program having a positive slack condition. Accordingly, only experienced personnel should be used in interpreting slack and translating it into schedule or resource allocation changes.

PERT Coordination

Continuing coordination between the planning and scheduling functions cannot be over-emphasized. Other organizations also will become more closely involved with scheduling as the regular cycle of PERT operations continue and become a "way of life". By the regular use of networks and data in scheduling meetings, they become primary management tools in scheduling.

Rescheduling

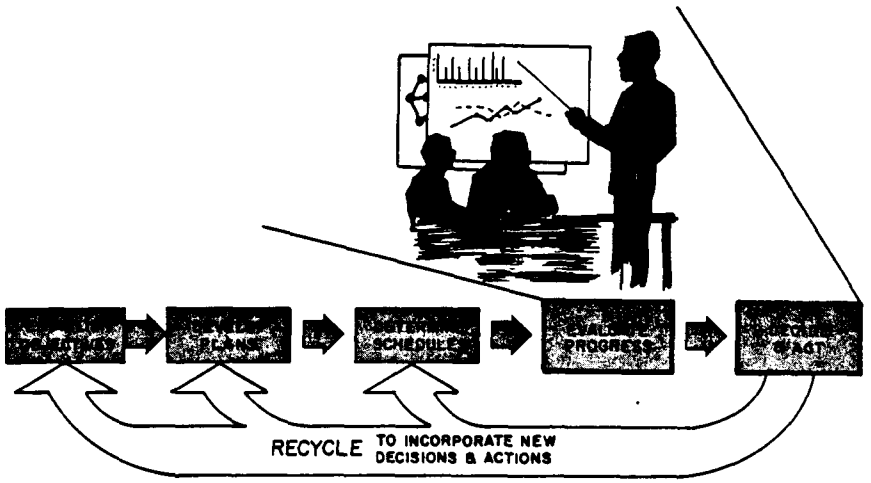
The need for updating the schedule occurs as a program proceeds for the following general reasons:

- change in the prime or supporting objectives;
- change in plans to achieve objectives;
- schedule slippage or gains affecting the timing of related activities in the plan which require rescheduling;
- change in funding.

The method for rescheduling is similar to the original scheduling process. Formal procedures for rescheduling should be established for adjusting schedule and communicating these adjustments to others involved in the program. These formal procedures should also permit ready appraisal of the effect of the rescheduling changes by all personnel concerned.

CHAPTER V

REGULAR PROGRESS REPORTING, ANALYSIS, AND MANAGEMENT ACTION



The program evaluation process is the means by which management can assure that:

- all participants in a program are working together toward a common goal or goals;
- intelligent use is made of resources, priorities, and delegated authority;
- staff and functional specialist work is integrated, coordinated, and evaluated to support the timely decisions required at various levels of responsibility;
- all component efforts are proceeding so that they will integrate, when required, into a workable end item.

Effective program administration and control requires an upward flow of selective data. It is used by progressively higher levels of management in supporting and guiding the efforts of those responsible for specific program elements. Each successive supervisory or operating manager has a responsibility corresponding to his delegated authority to:

- assess progress and performance;
- take action within his responsibility;
- provide status information and unresolved problems with relevant interpretative material to the next higher level of management.

From this flow of data, the need for action and essential changes in level of effort can be determined. New direction and actions altering schedules, technical performance or costs for the overall program objectives must originate at the proper level of program management and be communicated to the operating organizations.

Determination of Information Requirements

The best approach in determining the information requirements for various levels of management is to consider their informational needs. Once the basic requirements have been identified and procedures established for collecting and summarizing the data, means for translating the information into forms and reports suited to the transfer of knowledge must be established. Generally, managers at any level want only the information from PERT which concerns their activities and responsibilities. This information must be in understandable form and easy to use. Quality rather than quantity of the reports should be stressed.

Objectives and Requirements

Decisions for solving management problems are based on expert opinions and judgements developed from the facts presented and the related past experience of the managers. Objectives, and plans for their attainment stem from the work breakdown structure and become progressively more detailed as they are communicated

downward through the organization structure. The reverse is true of progress reporting and evaluations which are communicated upward through the organizational structure.

The flow of information must be maintained at all times. Program managers must provide top-down orders or instructions specifying what is to be done and the information they require. The upward flow must provide facts on actual progress and forecasts for efforts not yet completed or undertaken. These facts, in turn, generate new or revised top-down instructions.

The analysis and presentation of facts in consistent summary type reports with explanation of problems, provide higher levels of management with a reliable basis for program decisions. Features of PERT which contribute to effective reporting and evaluation include the following:

- network plans, against which accomplishments can be reported;
- automatic identification of deviations from scheduled plan and potential trouble areas;
- use of a common format and language.

With PERT, a program is considered in detailed segments as well as in the aggregate. Definitive measurements of progress and assessments are first obtained for each detailed segment of the program. This information summarized at successively higher levels until an evaluation or synthesis can be made for all program elements and the whole program. A uniform reporting format must be used by all participating organizations, as well as common units of measurement (e.g., time, manhours, etc.), to facilitate consolidation and summarization of the data, either manually or by computer.

Progress reports provide, (a) information on activities completed or scheduled for completion during reporting period, (b) a forecast of those scheduled for the next reporting period, (c) any changes in the scheduled plan and (d) any changes in the estimated activity times. This places emphasis on the serious schedule problems of the performing units and their supervisory levels of management. It also pinpoints the areas for critical analysis in terms of planned application of resources, productiveness, accuracy of estimates, and the effectiveness of all levels of management.

Data Summarization and Output Reports

Management confidence in summary reports and evaluations depends upon the assurance that the data have been derived on a realistic basis. This realism begins in the detailed network level where estimates and actual meansurements are based on relatively small, easily recognized work segments. Requirements can be estimated and progress measured more precisely for a task of approximately one-month duration than for one which may involve four months or more.

Through a progressive summarization process, it is possible to communicate information required by successively higher levels of management on a "management-by-exception" basis. Detailed information is always available to higher organizational units on a required basis. All organization elements concerned with interface events should receive information on the status and outlook for interface events. Each report should be accompanied by a brief narrative analysis, including recommendations and alternative solutions by subordinate managers, when appropriate.

A program may involve several networks with several hundred events and activities. Use of high speed data processing equipment makes it possible to process a large number of variables and provide data for evaluating status. This affords comprehensive program information to management in a timely fashion.

The information reporting system furnishes answers to the following kinds of questions for the specific area under consideration and for the program as a whole:

- Is the actual accomplishment meeting current performance, schedule, and cost commitments? If not, what is the extent and significance of the differences?
- What is the outlook for meeting future performance, schedule, and cost commitments?
- Is the outlook improving or getting worse, and why?
- What major factors are controlling time and cost requirements?

In summarizing information for display purposes at higher management levels, the following guidelines should be observed:

- graphic displays are preferable to tabular numerical values that require study and analysis;
- all management levels require timely summaries on the overall program status. Specific levels need summaries of specific areas of the program within their jurisdiction as well as summaries of any specific problem. All want and need the required information in clear, concise, and understandable form;

- the information should be predictive as well as historical, should be developed only to the level of detail which is essential for apprising specific levels of management.

The Output Reports permit an immediate appraisal of status against the scheduled plan by comparison of the actual or expected completion dates against latest allowable dates for the major events. The principal problem areas can be isolated through critical and slack path analyses, and identified to the lowest level of management responsibility.

The standard PERT computer Output Reports should include:

- a slack sort listing all events or activities in sequence from the least positive or most negative slack to the most positive;
- a chronological listing of all events or activities;
- a listing of all events by event number.

Examples of these Output Reports are shown in Figure V. 1. These are considered basic and minimal. Others can be developed to meet the needs of specific users.

Accompanying analytical reports and back-up interpretation material must supplement these Output Reports with the following information:

- summaries of the current status in relation to scheduled plan as well as the outlook for achieving major goals; brief explanation of the reasons when current outlook for project completions differs from the preceding outlook;
- statements of problems (the causes, the preventive or corrective action being taken and by whom, the anticipated date of problem solution, and impact on other sequential work);
- recommendations for action on the part of higher levels of management, and alternative solutions to technical problems which may have arisen.

PERT Milestone Reports and Schedule Outlook Reports (Figures I. 4 and I. 7) provide situation summary and historical comparisons of the schedule dates of the project with outlook completion dates, and are extremely effective in presentations.

Periodically, the entire PERT reporting system should be reviewed to assure that reporting procedures have not become outmoded and that information requirements for management are being satisfied. Re-grouping of data from the regular reporting process or the deletion or addition of Output Reports to individual organizations may be necessary.

Reporting Frequency

Due consideration must be given to the reporting interval or frequency by operating management. A bi-weekly reporting cycle is quite common, although weekly and monthly cycles are often used. The performing levels and middle managers may require more frequent reporting than top level management. The frequency of reporting may be influenced by the following:

- requirements of the customer;
- program duration;
- magnitude and complexity of the program;
- criticality and dynamic nature of the program;
- time required for data processing;
- degree of detail in the report;
- status of this program in relation to other priority programs.

Progress reports must be timely in relation to the cut-off date used in preparing reports. An indication of an approaching problem today is more valuable than a detailed blueprint of the situation weeks later.

EXAMPLES—PERT COMPUTER READOUT REPORTS

DATE 06/16/63 **PERT SYSTEM** SEQUENCE: SLACK

EVENT	NOMENCLATURE	EXPECTED DATE	LATEST ALLOWABLE DATE	SCHEDULE DATE	SLACK
01-173	CHECK DETAILS	09/23/63			-14.0
01-175	DETAILS APPROVED	10/07/63			-14.0
01-176	ENGINEERING RELEASE	10/21/63			-14.0
01-154	DETAILS APPROVED	08/26/63			3.0
01-156	ENGINEERING RELEASE	09/10/63		09/30/63	3.0
01-133	PURCHASING SPEC. REVISED	09/07/63			7.0
01-134	PURCHASING SPEC. REVISION APPROVED	09/15/63			7.0
01-135	ENGINEERING RELEASE	09/20/63			7.0
01-138	FINAL DESIGN INFO. TO VENDOR	10/07/63			7.0
01-130	COMPL. LAYOUT REVISION	08/19/63		11/04/63	10.0
01-131	LAYOUT APPROVED	08/26/63			10.0

DATE 06/16/63 **PERT SYSTEM** SEQUENCE: EXPECTED DATE

EVENT	NOMENCLATURE	EXPECTED DATE	LATEST ALLOWABLE DATE	SCHEDULE DATE	SLACK
01-130	COMPL. LAYOUT REVISION	08/19/63		11/04/63	10.0
01-131	LAYOUT APPROVED	08/26/63			10.0
01-154	DETAILS APPROVED	08/26/63			3.0
01-133	PURCHASING SPEC. REVISED	09/07/63			7.0
01-156	ENGINEERING RELEASE	08/10/63		09/30/63	3.0
01-134	PURCHASING SPEC. REVISION APPROVED	09/15/63			7.0
01-173	CHECK DETAILS	09/23/63			-14.0
01-135	ENGINEERING RELEASE	09/28/63			7.0
01-138	FINAL DESIGN INFO. TO VENDOR	10/07/63			7.0
01-175	DETAILS APPROVED	10/07/63			-14.0
01-176	ENGINEERING RELEASE	10/21/63			-14.0

DATE 06/16/63 **PERT SYSTEM** SEQUENCE: EVENT

EVENT	NOMENCLATURE	EXPECTED DATE	LATEST ALLOWABLE DATE	SCHEDULE DATE	SLACK
01-130	COMPL. LAYOUT REVISION	08/19/63		11/04/63	10.0
01-131	LAYOUT APPROVED	08/26/63			10.0
01-133	PURCHASING SPEC. REVISED	09/07/63			7.0
01-134	PURCHASING SPEC. REVISION APPROVED	09/15/63			7.0
01-135	ENGINEERING RELEASE	09/28/63			7.0
01-138	FINAL DESIGN INFO. TO VENDOR	10/07/63			7.0
01-154	DETAILS APPROVED	08/26/63			3.0
01-156	ENGINEERING RELEASE	09/10/63		09/30/63	3.0
01-173	CHECK DETAILS	09/23/63			-14.0
01-175	DETAILS APPROVED	10/07/63			-14.0
01-176	ENGINEERING RELEASE	10/21/63			-14.0

FIGURE V.1

Information Center

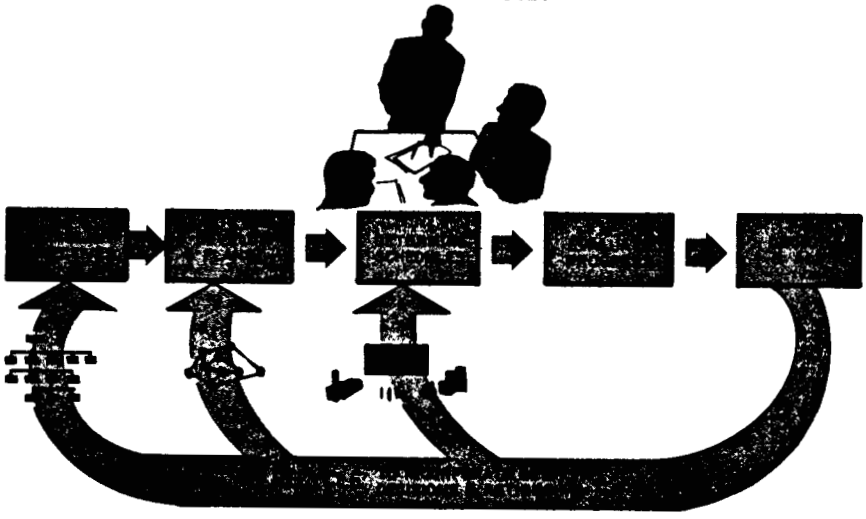
An information or management center can serve a variety of purposes, such as a display room for program status and outlook, a conference room, a means of keeping participants aware of the need for the review and control functions of management, or ideally, as a complete coordination, communication, and evaluation center for program managers. Management in government and industry typically has found it desirable to hold weekly briefings. Higher levels of review are conducted on a monthly and on-call basis.

Regularly scheduled meetings conducted within an information center provide continuous effective communication. As a meeting place for responsible managers, their key assistants, and representatives of higher and lateral authority, the information center can provide an effective means for periodic transfer of information to assure program integration. It can serve as the focal point where management can bring together results from channels of reporting, key participants, and higher levels of management for program review. Executive attention can be drawn to actual and potential problems, alternative or recommended solutions, policy decisions, problems of coordination, or any other situation which requires higher level management decision or action. Major problems requiring action on the part of higher or lateral authority can be identified and communicated to those involved. On-the-spot decisions can be made and communicated to those responsible.

Decisions and observation of the program manager and other key personnel are recorded and subsequently transmitted to those responsible for action. The immediate objective of these meetings is to correlate all efforts and keep them moving toward the program goals, thus assuring that effective and efficient control over the program will be maintained.

CHAPTER VI

RECYCLING OF THE MANAGEMENT PROCESS TO INCORPORATE NEW ACTION



Despite efforts to adhere to the scheduled plan as originally developed, requirements for changes in the scheduled plan, or even the objectives, arise during the course of accomplishing a program. In some instances these may stem from higher authority. Normally, requirements for changes will result from one or more of the following typical reasons:

- inaccurate estimates of scheduled times or required resources;
- inability to apply resources as planned;
- unanticipated technical problems;
- inadequate plan;
- insufficient definition of objectives;
- other unforeseen adverse events (strikes, fire, etc);
- necessary or desirable technical redirection.

Each requirement for change constitutes an opportunity for early improvement of the conduct of the program. If the scheduled plan is changed, intelligent and expeditious effort is required to assure that the corrective action decided upon will correct causes of the problem rather than treat the symptoms. An alert manager will remain sensitive to the possible opportunities present in these requirements for change. He may be capable of making or recommending adjustments in the program which will offer increased benefits in performance or decreased time and cost.

Recycling of the Management Process

The recycling process, as it affects the formal scheduled plan, will vary in complexity from a simple rescheduling process back through replanning and possibly even the redetermination of objectives.

These types of management action are listed in order of increasing management complexity:

- rescheduling within the manager's authority;
- rescheduling affecting authority in other organizational components;
- replanning within the constraints of the established plan;
- replanning without the constraints of the established plan;
- redetermination of supporting objectives;

- redetermination of prime objectives;
- some combination of these.

A change involving management action of any greater complexity than "rescheduling within the manager's authority", will require the taking of all interrelated actions appearing above it in the list shown. It is emphasized that there is no short-cut to this procedure.

As a principle, effective adjustments in the scheduled plan should be accomplished with minimal recycling in the management process. Before a particular change or set of changes, is decided upon for incorporation in the scheduled plan, possible alternatives should be considered. The effect of each of the possible alternatives can be rapidly assessed with simulation methods before adoption. After study of possible alternatives, the management process of objective determination, planning, and scheduling must be recycled to the degree necessary to incorporate logically the new management action in the scheduled plan.

Incorporating New Management Action

When management at any level desires to incorporate a new management action in the scheduled plan, several problems arise. The change must be:

- documented as a recommended change;
- coordinated with concerned organizations;
- authorized as an approved change;
- incorporated in the scheduled plan and other related official documents.

Procedures should provide clear guidelines for documentation of proposed changes, authorization for change approval, and the processes by which new management actions are to be incorporated in the scheduled plan and other related documents. The procedures must clearly distinguish the degree of authority of a particular manager from that of higher levels of management. Proposed changes must be communicated up to the management level which authorizes the changes. Conversely, direction and authorization must be communicated back to the operating level. Incorporation of any new action in the scheduled plan requires understanding of the delegation of authority by the organization controlling the entry of changes into official documents governing the conduct of the program.

Formal procedures are required and the same control over these must be exercised as was exercised in evolving the original scheduled plan. These procedures apply to all organizational levels for a program. More than one schedule of activities may other wise result with management unaware that more than one schedule is currently governing the same organization. This must be avoided by whatever means become necessary.

When recycling action is of a drastic nature requiring a change in more than one level of the work breakdown structure (i.e., because of replanning or redetermination of objectives), close liaison with all effected management levels is essential. Conferences must be held to assure an understanding of the problems of participating organizations. Subsequently, documents summarizing the results and outlining required changes should be produced.

A particular level of management may recognize the need for new action and require help or authority from a higher level. In this case, when immediate approval of the required change is not possible, a statement of the problem and related pertinent facts should be prepared. Required specification and adequate justification should be included. Such requests may accompany management summary reports to higher levels.

Identification of problems pinpointed by program evaluation as discussed in Chapter V will frequently signal the need for the origination of changes or recommendations for changes by a manager as discussed earlier in this Chapter.

Simulation of Alternative Management Actions

Normally, a number of alternative actions are contemplated by management, and only one can be chosen as a realistic solution. Simulation offers a method for testing these alternatives and evaluating the effects of each. Simulated time changes in activities, or the addition or deletion of activities may be fed into the computer in the same manner as up-dating information. Analysis of the outputs of the simulation will indicate the new situations which would be expected to occur. Simulation can frequently be accomplished manually if small networks are involved.

This tool is particularly useful when unexpected troubles occur and corrective action is needed in a hurry. The ability to quickly assess the probable impact of proposed or incorporated changes and give rapid evaluations of alternatives to management makes simulation invaluable. Simulation can show the impact of alternative decisions on the total program thereby permitting the highest levels of management to evaluate various courses of action as they affect the final objective.

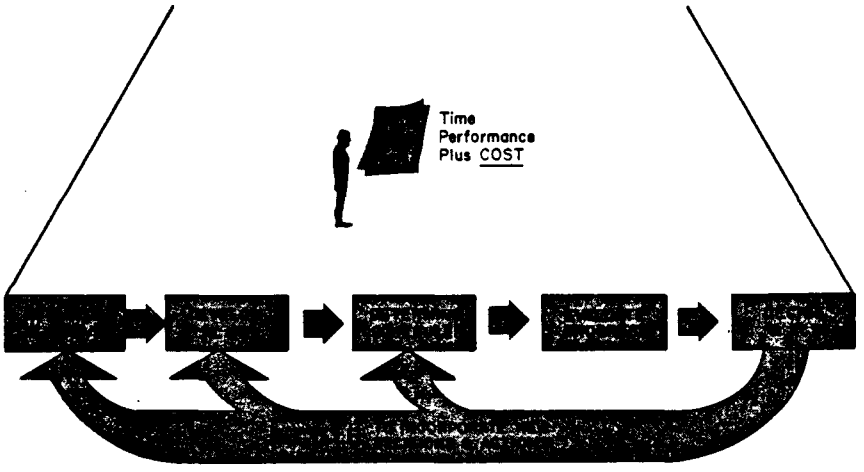
Simulation of the effect of proposed changes to scheduled plans before incorporation of them as new management action should be required. Specifically Engineering Change Proposals (ECPs) should be simulated before they are submitted to higher level management for approval.

Actions Resulting from the Recycling Process

Generally as a result of the recycling process management decisions could result in a change of the schedule, the network plan, costs, the prime or supporting objectives, or some combination. Although recycling is not completely accomplished by PERT, making decisions regarding changes and the communication of change are facilitated.

CHAPTER VII

PERT COST



Complex programs can be managed most effectively only if project managers have a common framework from which to plan and to control the schedules and costs of the work required to achieve the performance objectives. Benefits can be increased when PERT Cost 1/ is included as part of the total planning and control system.

Managers at all levels need techniques at all stages in a project to:

- define the work to be performed;
- develop realistic cost estimates based on the resources planned to perform the work;
- determine where resources should be applied to best achieve the time, cost, and technical performance objectives;
- identify those areas developing cost overruns in time to permit corrective action.

For example, managers at each level must be able to determine:

- whether the current estimated cost for completing the entire program is realistic;
- whether the program is meeting the committed cost estimates, and, if not, the extent of any difference;
- whether requirements for manpower and other resources have been planned realistically to minimize premium costs and idle time;
- how manpower and other resources can be shifted to expedite critical activities;
- how manpower and other resources made available by changes in the program tasks can be best utilized.
- the consequences of alternative courses of action.

PERT Cost serves these purposes. It can provide realistic cost estimates and periodic cost reports which relate costs incurred to progress achieved, and it can forecast the total cost of the program.

Characteristics of the PERT Cost System

PERT Cost utilizes the work breakdown structure and the network as the common framework for planning the schedule and cost of the program. As in the PERT system, the program is first defined and then broken down into end item subdivisions and then into the work packages to be assigned to first-line supervisors. These work packages are then represented by activities (one or more) on a conventional PERT network to identify the interdependencies in the program and the sequence in which the work will be performed.

1/ "DOD and NASA Guide PERT Cost Systems Design", dated June 1962, Government Printing Office.

After the network has been prepared and the schedule for the program has been established, the responsible operating and management personnel develop cost estimates for each work package, basing the costs on the manpower and other resources required to perform the program on schedule. These estimates are made by first determining the manpower, material, and other resources required to perform each work package. The resources estimates are then converted to dollars to determine the direct cost of each work package. Indirect costs are added to work packages where such accumulation is possible by existing accounting procedure, or as required by contract. All other indirect cost are pro-rated at summary level of the program on the basis of total program indirect costs less indirect cost already accumulated or assigned. Data submitted to the Government will understandably include all cost.

Separate cost estimates are not as a rule, necessary for each activity in a work package since this could result in excessive detail and unrealistic accounting effort.

The cost estimate for a work package is affected by both the elapsed time required to perform the work package and the calendar period during which the work package is scheduled to occur. The latest schedule status is considered in preparing cost estimates for work packages and in planning the allocation of manpower and other resources. Operating and management personnel analyze the estimates to eliminate unnecessary manpower costs and premium payments for materials and services.

For example, monthly manpower requirements are totaled by skills and examined to minimize unnecessary overtime and unnecessary hiring caused by manpower peaks followed by layoffs. This manpower "smoothing" is accomplished by rescheduling slack activities to periods when the skills are not required by critical activities. Rescheduling slack activities can also eliminate or reduce premium payments for materials and services.

Periodic comparisons are made of the actual costs incurred for each work package with their current estimates. This comparison establishes the cost status of the program and identifies any incurred cost overruns. Estimates of the cost needed to complete work not yet performed are also obtained in order to predict future cost overruns and to identify difficulties in the performance of critical work packages early enough to take constructive management action.

The account code structure consists of numbers which are used for charging (charge numbers) and summarizing (summary numbers) the costs of a program. Charge numbers are assigned to each work package at the lowest level of subdivision, and summary numbers are assigned to each end item subdivision on the project work breakdown structure. All costs are first collected or recorded under the charge numbers assigned to the work packages and are later summarized for each end item subdivision in the work breakdown structure for use by higher levels of management.

The level of detail to which it is desirable to apply PERT Cost is largely a matter of judgement, and varies from program to program, from one part of a program to another, and from the proposal preparation stage to the execution stage of the same project.

PERT Cost Reporting

The Output Reports shown in Chapter I have been selected from among those included in the "Draft Supplement No. 1 to the DOD and NASA Guide PERT Cost Output Reports. This draft document has been printed for use on present programs and contracts of the Department of Defense, distribution to Government agencies for more detailed review and distribution to the Bureau of the Budget so it may be reviewed by the Industry Advisory Council. It is not intended as a requirement that all must be used. Agencies, Services and Managers may only wish to require a selection of them to be reported on. It is intended that the system be capable of providing for all of them upon demand.

It is not necessary that the data submitted on these reports be presented internally to managers in these forms. Rather the data, with these reports and this system to back it up, should be presented to management in the most accustomed form possible in order to take full advantage of the managers experience.

Periodic management reports make it possible for managers to anticipate cost overruns and underruns. An example is the Management Summary Report (Figure I. 3) which shows the overall schedule and cost status of both the program as a whole and of each of the major component items. It also indicates the problem areas that require management attention.

The Report provides each manager with the following information relative to his areas of responsibility:

- the cost overrun or underrun to date (a measure of cost performance), through a comparison of the planned costs with actual costs for the work performed;

- the projection of total cost overrun or underrun which is obtained by comparing an original cost estimate (planned cost) with the actual costs plus the estimated costs to complete the program (latest revised estimate);

- the amount of schedule slippage as indicated by the difference between the established schedule for project completion and the present expected date for project completion (earliest completion date);

- the identification of trouble spots - that is, identification of those areas of the program where the cost or time status requires management attention.

Management Summary Reports are prepared for managers at each level or echelon of the program structure. Each Management Summary Report will normally be accompanied by a brief written analysis. One report is prepared, for example, for the entire System (level 0). At level 1, a similar report is prepared for each major element of the program, such as Launch Equipment, Aerospace Vehicle, Operational Site, etc. At the next lower level, level 2, the major elements of the program are subdivided again and a Management Summary Report is prepared for each manager to whom responsibility is assigned. The Aerospace Vehicle, for example, is divided into elements such as Propulsion, Re-entry, Body, and Ballistic Shell. The Ballistic Shell is further subdivided and management reports are prepared at such lower levels of the program as are considered necessary by the program manager. In analyzing the status of a program, the responsible manager would examine the reports for those end items where trouble is indicated. He would then refer to the lower level reports as required to isolate the trouble.

Another management report is the Cost of Work Report which shows the appropriate manager:

- the planned costs to perform the work;

- the actual costs (expended and committed) to date;

- the value for work performed to date;

- the projection of costs to program completion, based on actual costs to date and estimates-to-complete for work not yet performed.

A comparison of the actual costs accumulated to date and the value for work performed to date will show whether the work is being performed at a cost which is greater or less than planned. Figure I. 5 illustrates an example of the Cost of Work Report.

The Cost Outlook Report (Figure I. 6) and the Schedule Outlook Report (Figure I. 7) show the trend of successive monthly projections of the time and cost to complete the work. Each month, new projections are obtained and these projections provide new entries for the Cost and Schedule Outlook Reports.

By relating the trend of these projections to previous management decisions, the manager can observe the effects of these decisions on the cost and schedule for the project. He can determine, on a month-to-month basis, whether or not the actions taken to control schedules and costs are producing the desired results.

Through the use of these types of reports a manager is able to determine the status of the program and to identify cost problem areas. Based on his evaluation, a manager may take any of the following actions to minimize the cost of a project:

- adjust the schedule of slack path activities to minimize the need for overtime or additional hiring;

- reallocate funds from areas of underrun to more critical areas;

- revise the planned resources for work packages by:

  - trading off interchangeable resources between critical and slack path activities;
  - increasing or reducing the planned resources for activities.

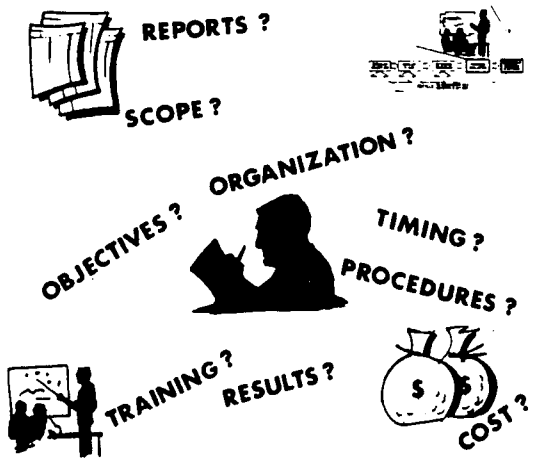
- revise network sequence or content by:

  - employing a greater or lesser amount of concurrence in performing activities;
  - modifying the specifications or methods of performing the work, thereby altering or deleting or adding activities.

Since the actions that a manager takes to correct problems often involve revising plans, schedules, and budgets, provision is made in PERT Cost for necessary recycling at regular intervals throughout the course of a program.

CHAPTER VIII

EFFECTIVE IMPLEMENTATION AND OPERATION OF PERT



In planning for PERT application, the desired objectives should be stated as specifically as possible. These objectives should answer such questions as:

- What are the expected or desired results from using PERT?
- What organizations will report PERT information?
- What existing reports, procedures, and methods will be replaced?
- Who will be responsible for operation of PERT, and what will be his authority?
- What will be the scope of the application: total program, selected critical sub-areas, etc. ?
- What are the system performance characteristics in terms of time required to go through one cycle of operation, operating costs, etc. ?

The initial and most significant step in the establishment of PERT is the issuance of policy statements by management. Such statements serve to endorse the use and benefits of PERT and officially acknowledge it as an authorized technique for program planning and control. Experience has shown that such statements can also serve as incentive to middle and working level management in effective initial acceptance and successful implementation.

In order to translate general policies into working operations, specific procedures must be developed for the operation of PERT within an organization. The responsibility for developing the initial procedures generally rests with an implementation team. The procedures should be designed to expedite the operation of PERT and must be fully compatible with the requirements of operating personnel and the capabilities of the data processing operation. Some of the areas where procedures should be specified are:

- preparation and transmittal of input data;
- reporting of status information and updating;
- distribution of output data.

Specific instructions for preparation of input forms and for interpretation of output forms should be issued. The responsibilities for the preparation and analysis of the forms, as well as the distribution of the forms and frequency of input and reporting, must also be specified. Although computers can be used to assist in processing large quantities of data, the computer is secondary. On a small program, processing of data can be done manually.

Organization and Personnel Requirements

The functional operation of a PERT system should be the responsibility of the normal supervisory staff and management personnel. The necessary skills are usually available within the organization. The performance of specific functions may be assigned to individuals who become the PERT operating group. The members of this group must be thoroughly knowledgeable in the mechanics of PERT including network development, calculations, analyses, and applications.

The presence of a small specialized PERT Staff Group or implementation team is normally required for the indoctrination and training of operating personnel. This Group also recommends procedures and usually monitors the implementation effort. On a continuing basis it provides guidance in:

- indoctrinating additional personnel;
- maintaining networks;
- preparing input data;
- analyzing outputs;
- preparing of management displays;
- assisting managers in identifying problem areas and suggesting alternative solutions supported by the available data.

The PERT Group may report to corporate management, to a program manager, or to an operating manager if the effort is solely within the province of one operating organization. The Group acts in an advisory capacity; line management has the responsibility for the implementation of PERT and for the effectiveness with which it is used.

PERT Staff personnel who have been most successful in the implementation and operation of PERT are found to have widely different backgrounds. The following characteristics seem to be paramount:

- interest in planning work;
- ability to deal effectively with people at all levels;
- analytical ability.

For large programs at least one member of the PERT Group should be familiar with data processing operations and procedures. Such a person can assist in suggesting good procedures and in solving the difficulties which will arise if a computer is used.

The task of preparing valid network plans, or of working with technical personnel in preparing such plans, requires a person who has the broadest possible knowledge of the work to be done, the organization structure. Persons who have had experience with the organization and who are technically qualified in at least some areas of the operation are very effective in network plan preparation.

Personnel who have experience and responsibility for performing the work are invaluable in determining the specific input data, such as time estimates for the activities. Clerical assistance is required to transcribe the data to the data transmittal work sheets.

The number of persons required to implement and operate PERT varies from organization to organization depending upon such factors as complexity of the program, existing organizational structure, level of detail, and the degree of similarity between PERT and existing procedures. Since many of its functions replace or streamline earlier procedures, the complement of existing personnel is often enough.

The importance of managerial support in making PERT work cannot be overstressed.

PERT Operating Standards

The PERT operation must meet certain fundamental criteria. These criteria are stated below in relation to the network(s), statistical data, and analysis outputs.

The work breakdown structure and the network(s) must:

- outline the complete, current, approved plan, which in terms of activities and events, indicates the step-by-step process of attaining the qualitative and quantitative objectives of the program;

- detail the current and projected division of labor between responsible organizations in a manner consistent with the objectives, plans, and schedules of higher level authority;
- break the program objectives into sequential and parallel activities and event which actually schedule, measure, and govern the conduct of work by responsible organization;
- indicate the relationships between supporting objectives and the end of work objectives;
- include only activities and events which have been defined by competent authority;
- provide the structure for a meaningful reporting system for program management use;
- be so constructed that they coordinate or interface with programs of lateral, higher, or lower level authority;
- be used on a continuing basis as an effective communication device to integrate the objectives and activities of the various program managers, their operating managers, and other external organizations concerned.

The statistical data must:

- be derived after definition of the work to be done within the activities to be accomplished;
- derive from an approved source, which is either the responsible organization having cognizance over the work or the organization performing the work;
- indicate accomplishments to date in terms of the events and activities in the network(s);
- retain the integrity of data through the manual or computer processing or handling to produce analytical reports;
- be regularly (normally bi-weekly or monthly) audited and updated.

PERT analysis output must:

- enable continual evaluation of current and projected program status;
- enable the preparation of program progress and problem reports to management on a cyclical basis;
- be regularly used by management in the decision-making process and the taking of necessary corrective management action to secure timely accomplishment of program objectives.

Implementation and Operating Costs

The most frequent question concerning the use of PERT is that of the cost of implementation and operation. The implementation and operation may initially cost somewhat more than an existing system since PERT may require greater planning skills and more detail. The benefits achieved should far outweigh the implementation and operating costs. In each case an estimate should be made of the actual cost of PERT implementation and operation in order to evaluate these benefits properly.

APPENDIX A

EXAMPLE APPLICATIONS OF PERT

The applications of PERT which have proven successful are many and varied encompassing virtually every field of human endeavor. Recent studies provide striking examples of profit improvement and time saving attributable to the use of PERT. An average time reduction of 22% as well as a 15% reduction in "expediting costs" on almost 50 projects were reported for Catalytic Construction Company. A 37% reduction in downtime, with a saving of some one million pounds of production in the shutdown of a chemical plant in Louisville, was reported for DuPont. A time reduction of 25% and estimated benefits of about $1,000,000 in construction of a plant properly timed to the growing season were reported for Sun-Maid Growers in California.

Some additional representative examples of PERT applications cover:

- weapon and space systems acquisition
- missile site activation
- atomic energy programs
- civil defense programs
- support equipment management
- maintenance planning
- training programs
- manuals and reports preparation
- salvage operations
- administrative planning
- military operations
- small business ventures

Weapons and Space Systems Acquisition

The Navy's Special Projects Office (SP) began applying PERT to major areas of effort early in the POLARIS program. Prior to that time a form of Gantt charting involving thousands of individual milestones was used as the primary method of planning and control. The task of assessing program status by continually updating and reviewing each milestone was laborious and taxed the limits of human comprehension. PERT provided a means of knitting these milestones into objective oriented plans enabling top management to readily determine the time phased relationship between tasks and the interactions between performing organizations. Computer processing of PERT data permitted timely analysis in terms of problem areas critical to the achievement of terminal objectives and greatly improved the ability of Special Projects to manage "by exception".

The many applications in the POLARIS program include, submarine construction, missile R&D, equipment development and fabrication through first article delivery, facilities construction and equipment installation, second source production planning and transitions from development to production contractors. Individual applications are tailored to the characteristics of the effort and organizational circumstances. For example, a major contractor may process his own data or inputs from several constractors may be correlated and processed by SP personnel. In all cases the PERT data is analyzed within SP together with other information to produce a continuous objective evaluation of the program.

Missile Site Activation

PERT was applied in part to the ATLAS E Program, but later and concurrently to the entire ATLAS F, TITAN I, TITAN II and MINUTEMAN Site Activation Programs. It is continuing in application today. These applications are considered particularly significant because PERT has been used as both a planning and monitoring tool in these programs, yet site activation occurs after site equipment has entered the production phase.

Although the actual PERT operation varied somewhat from program to program, the concept of operation as applied to TITAN I is considered generally representative of the methods used. Site activation networks were developed for each site and limited in scope to events which would occur on site. Within site, individual network(s) for each "hole" or silo were constructed, averaging about 450 events in size. Planning and monit ring are carried out at this level of detail, as well as at a higher level of integration. These networks are organized in such a way that they interface with construction networks managed by the Corps of Engineers and their contractors and with the planned delivery records on equipment end items which are maintained by the Integrating Associate Contractors and other associates.

PERT operation was, of course, tailored for the application. The tempo of the Site Activation efforts is so rapid that most of the PERT operation has been handled on a manual basis, with runs at periodic intervals also made by computer. In this way PERT is being used in an almost "real time" sense for accomplishing replanning and control, particularly in sites nearing turnover date to Strategic Air Command.

Atomic Energy Programs

PERT is being used in planning and controlling the development of virtually all new electronic and mechanical components of nuclear bombs and warheads. In complete weapons systems, new procedures incorporating PERT are being put into effect in cooperation with the DOD to assist in realistic scheduling and clear-cut understandings of responsibilities and interfaces. Interfaces and joint responsibilities with NASA and other agencies are being illustrated and clarified in the same manner.

Network planning and scheduling techniques are also being used for research and development, design and construction and the procurement and installation of equipment for the Stanford Linear Accelerator at Palo Alto, California. A building two miles long, a $114 million budget, and a completion date of 1966 are involved in the plan. This is one of several new projects using PERT.

For an entirely different example, the Atomic Energy Commission cites the Los Alamos Community Transfer. On September 29, 1962, the President signed legislation which authorized the AEC to terminate its ownership and management of the community of Los Alamos, New Mexico. While Los Alamos residents already had a degree of self-government, transfer of housing to private ownership and municipal facilities to the local Government or other local entity gives residents full responsibility for managing their own community affairs. Networks were prepared to plan the pre-transfer activities such as zoning and platting the community and classifying and appraising the property.

Civil Defense Programs

The Office of Civil Defense has combined PERT with other advanced management techniques to develop a total management information system for the National Fallout Shelter Program. It provides a unified planning and communications mechanism for coordinating the efforts of the large number of government agencies and numerous industrial organizations including over 600 architectural and engineering firms.

To assure full responsiveness to program management objectives the following features were incorporated in the system:

- The adaptation and tailoring of the PERT subsystem to reflect the fact that the Civil Defense Program requires not only horizontal management integration and control but also reaches down from top echelons of government and industry to actual shelters.
- The continuous updating of program information at the following levels:
  - top management data in the form of master summary networks and milestone charting,
  - gross time scaled network of the total program,
  - detailed network and associated computer printouts of project sub-areas.
- The use of both single and multiple time estimates in days rather than weeks for different portions of the program.
- Inclusion, within the overall system, of activities ranging from broad areas of research to specific production tasks.
- Development and use of a simplified computer output requiring no prior knowledge of PERT that shows only the activity numerical identification and descriptor and the required start and completion dates printed in the form of a schedule for a specific function code and in chronological sequence. This facilitates the assignment of manageable portions of the total job to the correct functional responsibility and permits the personnel involved to more readily assess their progress in implementing individual parts of the overall OCD task.
- Use of a variety of management tools, such as, Line of Balance and Gompertz projections, as subsystems of the total OCD Management System and the integration of this technique with the PERT Subsystem. The result has been a unified system encompassing development, production, procurement and logistic subsystems.

Support Equipment Management

The application of PERT to a major segment of the Equipment Management Program at Aeronautical Systems Division (ASD), Wright-Patterson Air Force Base, Dayton, Ohio has proved so successful the entire program is now covered. Since the annual management task approaches 1,000 line items of different types of support equipment, approximately 1,000 relatively small networks result.

PERT as applied to equipment management at ASD is unique. The full range of management actions including the preplanning, contractual and preproduction phases are covered in the PERT networks. The alternative procedures that exist for each phase have been made into standardized networks and precomputed to allow the managers to select the appropriate or recommended network. These networks are then linked together into

one network. Thus, lead time to deliver can be easily ascertained. Concise, comprehensive event coding speeds transmission of status and forecast of the total equipment management program, and also allows management to track and control progress on individual equipment items.

The U. S. Army Signal Corps Logistics Evaluation Committee developed a PERT extension called PERT/Comet - a device to enable the Signal Corps to manage multiple, small, equipment developments. This extension has found wide use in the new Electronics Command. Several unworkable clauses in previous contract forms posed difficulties for the Electronics Command contractors were uncovered and corrected.

Maintenance Planning

The Army Corps of Engineers applied critical path techniques to the annual inspection of a large hydroelectric generating unit. Features of the application included scheduling the orientation of personnel, preparing a work breakdown structure, determining manhour requirements and developing costs for normal and crash conditions. As a consequence of this application, the inspection that used to take 56 hours now requires only 24.5 hours.

The Materials Testing Reactor (MTR) and the Engineering Test Reactor (ETR) at the National Reactor Testing Station in Idaho provide environments for testing materials and components which will be used in power reactors. Recently, the use of network analysis in planning shutdown projects and scheduling manpower resulted in reducing shutdown time ten to fifteen percent. This amounts to a saving of $3,000 every four weeks on the MTR and a saving of $14,500 every six weeks on the ETR.

Training Programs

Air Training Command (ATC) is prepared to use PERT in the management of all its systems development support functions in the future and has already used the technique on some internal programs. PERT has proved adaptable to existing program-oriented management in ATC and has required no reorganization to support its use. The ATC System Staff Officer (SSO) is responsible for program management with the resources of one or more training centers available for support. The PERT networks are usually developed at training center level by the training manager at the center, the ATC SSO, and a PERT technical advisor from Headquarters, ATC.

The integrated planning capability in PERT proved extremely beneficial since approximately 65% of all training events interface with other activities. Some of the major systems under development since 1961 on which ATC has used PERT are the GAM-87 SKYBOLT, SM-80 MINUTEMAN, ERCS, portions of 480L, and the C-141 Jet Transport.

Manuals and Reports Preparation

The Bureau of Labor Statistics, U. S. Department of Labor, has effectively applied the principles of PERT to the world's largest labor statistics gathering and analysis operation. 1/ A comprehensive network was developed by BLS to plan its monumental annual adjustment and publication task which consists of several "sub tasks".

First, all statistics gathered throughout the year are checked and verified by computer. Then, the annual benchmark figures are gathered, entered and computed for all applicable statistical series. When computed, the benchmark figures produce a true mathematical "model" of the total industry. This is compared with the estimated figures that have been maintained throughout the year on the basis of the samples. After adjustment, this information is used to update the data from the previous year's publication and printed in the new book. Included are derived series adjusted for seasonal fluctuations, data on weekly earnings after taxes and adjusted for changes in the cost of living, and series showing manhour input by major industry.

The first PERT computer run showed a critical path of 420 days, representing an overshoot of the publication target by approximately 50%. The PERT listing quickly revealed a simple, but very critical fact: that conventional interdepartmental mail handling alone consumed 25% of the total projected time along the critical path. A more expeditious routing procedure was established and the critical path immediately dropped to 324 days, a gain of 96 days. Subsequent PERT analyses resulted in additional changes until a workable 269 day plan was established.

The Army Logistics Management Center is responsible for the development, preparation, and writing of standard Army Field Manuals in the logistics area. ALMC used PERT to investigate and schedule the work involved in the combination of in-house and contract work required to prepare a field manual. Once the sequence, interdependency and time for tasks was determined, a schedule was thus prepared for future manual preparation.

1/ Application Brief: "PERT In Action at the Bureau of Labor Statistics, U. S. Department of Labor", International Business Machines, Inc.

Salvage Operations

A barge, containing four large cylinders of deadly chlorine gas, had sunk into the mud of the Mississippi River near Natchez, Mississippi. Efforts to locate and raise the cylinders had failed, so The Army Corps of Engineers was called to do the salvage job and used critical path techniques to interface the activity. Cooperating with the Corps of Engineers were the Navy, Air Force, and Coast Guard. U. S. Public Health Service was assigned the job of responsibility for public safety. Also involved were the Mississippi National Guard, the Red Cross and the State authorities of Mississippi and Louisiana. The Air Force flew in the required materials, the Navy used magnetic detection devices to locate the sunken barge (corroborated by Navy divers), and the Army Engineers began the raising and salvage. The operation was successful and one after the other of the potentially deadly cylinders were raised and taken away.

Administrative Planning

PERT has been used by the Office of Defense Research and Engineering for the administrative actions involved in the processing of a weapon system proposal by a military service through the DOD approval phase and initial feasibility stage.

Another example of such a use of PERT was the administrative planning of a POLARIS capability in the Pacific Ocean. The PERT network, prepared in the fall of 1961, gave clear insight into the many aspects of establishing such a capability and greatly assisted in the formulation of more detailed plans.

Military Operations

The success experienced thus far in applying PERT to administrative planning tasks and those once-through tasks not of a research and development nature suggests that the technique might be very useful in areas of operational planning by military staffs.

There are several areas in military planning in which basic PERT can be very beneficial. The preparation of operational plans for large-scale military operations is extremely complex and can involve many different actions and decisions by various commands and staffs located in far-flung areas of the world. In preparing such a plan, there are also many dependencies and interrelationships among the events and activities that will appear in a network depicting the preparation of the plan.

Small Business Ventures

PERT applications to small business ventures cover a wide range of operations. Some such applications which illustrate the versatility of this tool include the planning, scheduling, and monitoring of:

- a play from casting through opening night,
- the establishment of new business locations and outlets,
- the introduction of new products,
- house construction, modifications, and repairs,
- advertising campaigns,
- management operations,
- the receipt, classification, and handling of materials, and
- book publishing.

Potential commercial applications of PERT by business management are virtually unlimited, and the usefulness of PERT will undoubtedly continue to grow with increased awareness of areas in which this management tool can make a significant contribution.

APPENDIX B

SLACK CONCEPT AND SLACK ANALYSIS

Introduction

The longest time path or sequence of activities through a network is called the critical path. This is the path which controls the completion date for the program represented by the network since all other paths are of less time duration. Should the length of time for the critical path be the same as the established completion date for the network, there will be no "time to spare". This "time to spare" relative to the established completion date is called slack time. In the example above, the slack time for the critical path would be zero. The case may also exist where the length of time for the critical path exceeds the established date for completion. In this case the critical path is said to have "negative slack". There is no "time-to-spare", in fact, a projected time slippage condition beyond the established completion date exists. In like manner there can be "positive slack" where the time duration for the critical path is less than the established completion date, indicating that the network activities will be completed with "time to spare."

Each series path in the network will have a slack value in relation to the established completion date for the program represented by the network. In this respect each and every series path has a measurable "degree of criticality" which can be either positive, zero, or negative. By definition, the longest time path would be the most critical in relation to the established completion date and hence is called the "critical path". All other paths which are of less time duration than the critical path, are therefore called "slack paths." Two or more paths may have the same time duration and will therefore have the same slack value. Should these same paths be the longest time duration in the network, there will be two or more "critical paths" for the same network.

It should be emphasized that the slack time for a series path pertains to the entire path and not to any one event or activity in particular. Any change in the activity time for any one particular activity in the path series will change the slack value for the entire path.

In Figure B. 1, the value of slack is zero for the path of Events 112, 114, 115, 117, and 119. Since this is the longest time path through the network, it is the critical path. Other paths through this network have slack ranging from 0.3 (112, 113, 114) to 4.4 (112, 118, 119) weeks.

Schedule requirements or development difficulties often result in situations where T_E for the end event is later than T_L, or where S_E is later than S_L. In these cases, the end event is expected to occur behind schedule unless some adjustments are made in the plan. When T_L's are calculated for the remainder of the network, one or more paths will have negative slack. Analysis of the negative slack paths will show the manager which activities require additional effort in order to accomplish the program on schedule.

Critical Path Analysis

The activities in the critical path should be reviewed by asking the following kinds of questions:

- Is the sequence of the activities in a "must" or "desired" order? If in a "desired" order, can the activities be sequenced in parallel with others in the critical path? If they can be sequenced in parallel with others, what added risk is being assumed and what is the effect on resource planning?
- Are the time estimates for the activities realistic? Can the times be shortened by adding resources? Does a decrease in time increase risk in meeting performance or reliability?

Slack Path Analysis

Analysis of slack in paths other than the critical paths is also important to ensure that the program is being executed in the most efficient manner. For example, no overtime should be allowed in an area where significant positive or zero slack is indicated. If the positive slack is considerable, one should consider the possibility of reducing the level of effort in that area and using the resources in alternative areas of effort to minimize idle time.

Slack Trend Analysis

The trend of slack, particularly on critical individual activities or events should be closely watched. Rapidly decreasing or increasing slack should alert management to changes in resources requirement and real and potential problems. Slack trend analysis makes it possible to pin point situations requiring timely management action.

Use of the Slack Concept

Other time as well as other resource considerations are inherent in each of the analysis routines mentioned above. Certain established contractual or other type working relations also should be taken into account before corrective management action in replanning or rescheduling of activities. These constrain, in many instances, the speed with which corrective management action can be taken even after a decision to make an adjustment in the program. PERT can give management early warning of these adjustments.

The correct use of the slack concept and slack analysis can be of great value to management in preventing program imbalance from:

- over-concentration on a single critical path;
- failure to realize that there is more than one limiting path in a program;
- premature withdrawal of resources from an activity or activities of the program in which high positive slack values are present.

Over-emphasis on the slack path concept must be avoided. Calculations of critical and slack paths in PERT consider only the constraints in the program which are represented on the network. These constraints reflect the technical dependencies and interrelationships which are inherent in the work to be performed. In addition to these constraints, factors such as the availability of particular resources and facilities in specific calendar time periods are major considerations in identifying the true critical and slack paths of the program. Because of this, there is a danger in thinking that the critical and slack calculations derived from a PERT network will automatically indicate the true time available for moving activities either backward or forward in calendar time periods. Before a realistic slack figure can be derived for a program, it is important to review not only the technical constraints in the program itself, but also the flexibility available in scheduling particular resources and facilities at varying time periods.

For example, a manager is responsible for an activity which lies along a path apparently containing positive slack of three weeks. The impression is created that he could begin that activity three weeks later than the scheduled start date without necessarily causing a delay in the program as a whole. However, if the activity is actually begun three weeks later, those resources necessary to complete the activity may have been scheduled for utilization elsewhere in accordance with the original schedule plan.

NETWORK SHOWING EXPECTED DATE, LATEST ALLOWABLE DATE, AND SLACK

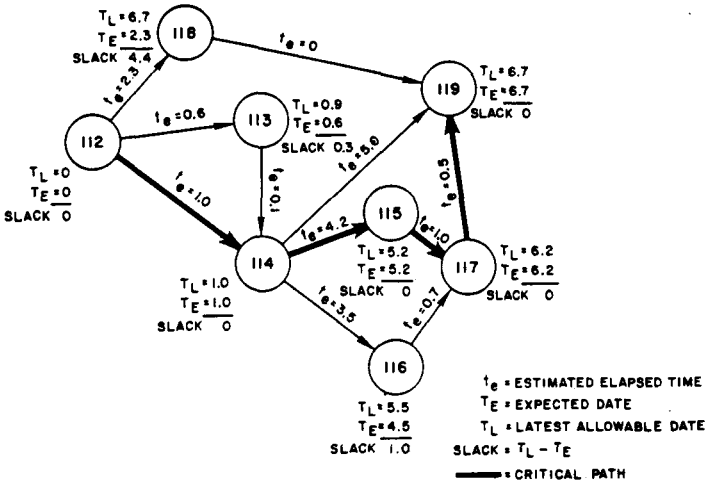


FIGURE B.1

APPENDIX C

PERT OPERATING PROCEDURES

I. Implementing

A. Preparing the Work Breakdown Structure, Constructing Networks, and Estimating Time

1. Proposal request and government requirements are received by contractor management.
2. Contractor management reviews proposal request and issues instructions to operating units.
3. Project end items are defined, work breakdown structure is prepared, first-draft networks are constructed, and elapsed time estimates are made.
4. Networks, with time estimates and the work breakdown structure, are forwarded to Project Administration.
5. Networks from each of the operating units are integrated on the basis of common events within the framework of the work breakdown structure.
6. Network, time estimates, and activity and event descriptions are sent to PERT Service Group.
7. PERT data processing input forms are prepared with event numbers, activity descriptions, and time estimates.
8. Drafting of program network.
9. PERT input forms are sent to Data Processing for computation.
10. PERT computations are made for printout of activity t_e, activity completion T_E and T_L, activity slack, and beginning and ending event numbers.
11. PERT output is sent to PERT Service Group for accuracy check and network posting.
12. Network is posted with time printout information and critical path.
13. Posted network and time printouts are sent to Project Administration for review.
14. Network and printouts are reviewed for completeness.
15. Network, time printouts, and work breakdown structure are forwarded to management for evaluation. Planning data are reviewed and recycled if management directives so indicate.

B. Scheduling

1. Management approves network structure, technical approach, and critical path duration.
2. Schedules are established; T_S is assigned for activity start or completion and t_s for activity duration, where desired.
3. Network is posted with applicable t_s and T_S changes.
4. Network information is processed and sent to Project Administration.
5. Master (summary) schedule information is developed from processed data. Displays are prepared.
6. Master schedule information is sent to management for evaluation. Schedule is evaluated and recycled if management directives so indicate.

C. Evaluation and Reestimating

1. Management evaluates proposal information.
2. Costs are reestimated where replanning is necessary.
3. Reestimates are substituted for original estimates (or entered as simulated data) and the plan is reprocessed.
4. Technical approach is altered where necessary (if network structure is changed, recycle again). Once an acceptable plan has been developed, the proposal is submitted and the contract is negotiated. Cost estimates now become firm contract estimates.

II. Operating Phase

A. Accumulating Actual Data and Revising Networks and Schedules

1. Activity completions, activity additions and deletions, and schedule revisions on existing activities (either activities in process or activities not yet begun) are marked on a copy of the network.
2. Updated network is sent to Project Administration.
3. Updated network is reviewed for approval.
4. Updated network is sent to the PERT Service Group where redraft is begun, if required.

B. Network Updating

1. PERT input forms are prepared for new and revised activities.
2. PERT input forms are sent to Data Processing for computations.
3. PERT computations are made and time printouts produced.
4. PERT printouts are sent to PERT Service Group.
5. Network redraft is completed.

6. Network is posted with revised time information.
7. Posted network and time printouts are sent to Project Administration.
8. Network and schedule changes are reviewed and a schedule exception report is prepared.
9. Exception reports, printouts, and networks are sent to management and operating units.
10. Network changes are made where management redirects work effort.
11. Network changes are processed.

C. Reporting, Evaluation, and Replanning

1. Completed activity dates and revised estimates-to complete are supplied to Data Processing.
2. PERT reports are generated.
3. PERT reports are sent to Project Administration.
4. Reports are analyzed and management displays are prepared.
5. Reports and displays are sent to project and functional management.
6. All reports and displays are reviewed and information evaluated by management.

APPENDIX D

GLOSSARY OF SYMBOLS AND TERMS

Symbols:

- a = The optimistic time estimate for an activity when three time estimates are used.
- b = The pessimistic time estimate for an activity when three time estimates are used.
- m = The most likely time estimate for an activity when three time estimates are used.
- S_E = Earliest completion date for an activity.
- S_L = Latest completion date for an activity.
- T_D = Directed date for an event.
- t_e = Expected elapsed time for an activity.
- T_E = The expected date on which an event will occur.
- T_L = Latest allowable date for an event.
- t_s = Scheduled elapsed time for an activity.
- T_S = Scheduled completion date for an activity or event.

Terms:

Account Code Structure (PERT COST)

The numbering system used to assign summary numbers to elements of the work breakdown structure and charge numbers to individual work packages.

Activity

A work effort of a program which is represented on a network by an arrow. An activity may also simply represent a connection or interdependency between two events in the network. An activity cannot be started until the event preceding it has occurred.

Charge Number (PERT COST)

A number used for identifying the costs charged to a work package.

Commitment (PERT COST)

An obligation within a corporate or government organization to charge cost against a specific work package. This may be in advance of a legal obligation against the contract.

Constraint

The relationship of an event to a succeeding activity wherein an activity may not start until the event preceding it has occurred. The term "constraint" is also used to indicate the relationship of an activity to a succeeding event wherein an event cannot occur until all activities preceding it have been completed.

Cost Activity (PERT COST)

An activity which employs resources, the cost of which is a direct charge to the program.

Critical Path

That particular sequence of events and activities in a path that has the greatest negative or least positive slack; therefore, the longest path through the network.

Directed Date for an Event (T_D)

Date for a specific accomplishment formally directed by the contracting authority. A schedule date (T_S) which has been formally specified by contracting authority.

Earliest Completion Date (S_E)

The earliest calendar date on which a work effort (activity, work package, or summary item) can be completed. This date is calculated by:

- summing the scheduled elapsed times (t_s) for activities on the longest path from the beginning of the program or project to the end of the work effort; and
- then adding this sum to the calendar start date of the program or project.

For distant time effort where scheduled elapsed times (t_s) have not been established, expected elapsed times (t_e) will be used to calculate S_E.

Earliest Expected Date (T_E)

The earliest calendar date on which an event can be expected to occur. The T_E value for a given event is equal to the sum of the expected elapsed time (t_e) for the activities on the longest path from the beginning of the program to the given event. It is frequently transposed to a calendar date.

Estimate-to-Complete (PERT COST)

The estimated man-hours, costs, and time required to complete a work package or summary item, (includes applicable overhead except where only direct costs are specified).

Event

A specific, definable accomplishment in a program plan, recognizable at a particular instant in time. Events do not consume time or resources.

Expenditure (PERT COST)

Actual disbursement of funds of a contractor for in-plant or subcontract expense pertaining to a contract.

Expected Elapsed Time (t_e)

The elapsed time which an activity is predicted to require. The expected elapsed time is identical to a single time estimate for the work to be accomplished, or is derived from the calculation of a statistically weighted average time estimate, incorporating the optimistic (a), most likely (m), and pessimistic(b) estimates for the work to be accomplished $\left(\frac{a + 4m + b}{6}\right) = t_e$.

Interface Event

An event which signals the necessary transfer of responsibility, end items, or information from one part of the plan to another. Examples of interface events are the receipt of an item (hardware, drawing, specification), or the release of engineering drawings to manufacturing.

Joint Cost Activity (PERT COST)

Joint cost activity is one which shares resources in such a way that it is impractical to further allocate them to individual activities.

Latest Allowable Date (T_L)

The latest calendar date on which an event can occur without delaying the completion of the program. The T_L value for a given event is calculated by subtracting the sum of the expected elapsed times (t_e) for the activities on the longest path between the given event and the end event of the program from the latest date allowable for completing the program. T_L for the end event in a program is equal to the directed date (T_D) of the program. If a directed date is not specified, $T_L = T_E$ for the end event.

Latest Completion Date (S_L)

The latest calendar date on which a work effort (activity, work package, or summary item) can be scheduled for completion without delaying the completion of the program or project. This date is calculated by:

- summing the scheduled elapsed times (t_s) for activities on the longest path from the end of the work effort to the end of the program or project; and
- then subtracting this sum from the calendar end date of the program or project.

For distant time effort where scheduled elapsed times (t_s) have not been established, expected elapsed times (t_e) will be used to calculate S_L.

Latest Revised Estimate (PERT COST)

The sum of the actual incurred costs plus the latest estimate-to-complete for a work package or summary item as currently reviewed and/or revised (including applicable overhead except where direct costs are specified.)

Milestone

Milestones are synonymous with events in a network.

Most Likely Time estimate (m)

The most realistic estimate of the time an activity might consume. This time would be expected to occur most often if the activity could be repeated numerous times under similar circumstances.

Network

A flow diagram consisting of the activities and events which must be accomplished to reach the program objectives, showing their planned sequences of accomplishment, interdependencies, and interrelationships.

Optimistic Time Estimate (a)

The time in which the activity can be completed if everything goes exceptionally well. It is estimated that an activity would have no more than one chance in a hundred of being completed within this time.

(Over) Under Plan - The planned cost to date minus the latest revised estimate of cost to date. When planned cost exceeds latest revised estimate, a projected underplan condition exists. When latest revised estimate exceeds planned cost, a projected overplan condition exists.

(Overrun) Underrun (Projected) - See Projected (Overrun) Underrun.

(Overrun) Underrun (Work Performed to Date) - The value for the work performed to date minus the actual cost for that same work. Where value exceeds actual cost, an underrun condition exists. When actual cost exceeds value, an overrun condition exists.

Pessimistic Time Estimate (b)

An estimate of the longest time an activity would require under the most adverse conditions, barring acts of God.

Planned Cost

The approved planned cost for a work package or summary item. This cost, when totaled with the planned costs for all other work packages, results in the total cost estimate, committed under contract, for the program or project.

Projected (Overrun) Underrun

The planned cost minus the latest revised estimate for a work package or summary item. When planned cost exceeds latest revised estimate, a projected underrun condition exists. When latest revised estimate exceeds planned cost, a projected overrun conditions exists.

Scheduled Completion Date (T_S)

A date assigned for completion of an activity (accomplishment of an event) for purposes of planning and control within an organization. Where no specific date is assigned, $S_E = T_S$.)

Scheduled Elapsed Time (t_s)

The period of time assigned for performing an activity.

Slack

The difference between the latest allowable date and the expected date ($T_L - T_E$), or the difference between the latest completion date and earliest completion date ($S_L - S_E$). Slack is a characteristic, as such, of the network paths. Slack may be positive, zero, or negative.

Starting Event (Beginning Event)

An event which signifies the beginning of one or more activities on a network.

Summary Item

An item appearing in the work breakdown structure.

Summary Number (PERT COST)

A number which identifies an item in the work breakdown structure.

Value (Work performed to Date) (PERT COST)

The planned cost for completed work, including that part of work in process which has been finished. This value is determined by summing the planned cost for each completed work package. If a work package is in process, the part of its total planned cost which applies to work completed is approximated by applying the ratio of actual cost to latest revised estimate for that work package.

Work Package

The work required to complete a specific job or process, such as a report, a design, a documentation requirement or portion thereof, a piece of hardware or a service. A work package may consist of one or more cost significant activities. The content of a work package may be limited to the work which can be performed by a single operating unit in an organization or may require the contributing services of several operating units. The overall responsibility for the work content of a work package should be assigned to a single organization or responsible individual. It is the lowest level of identification of costs to work performed and is represented by a charge number related to a single summary number. The work package couples to the cost accounting system through the charge number and to the PERT network through the beginning and ending event numbers of activities in the package.

Work Breakdown Structure

A family tree subdivision of a program, beginning with the end objectives and then subdividing these objectives into successively smaller end item subdivisions. The work breakdown structure establishes the framework for:

- defining the work to be accomplished;
- constructing a network plan;
- summarizing the cost and schedule status of a program for progressively higher levels of management.